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MISSISSIPPI SOUND REMOTE SENSING STUDY

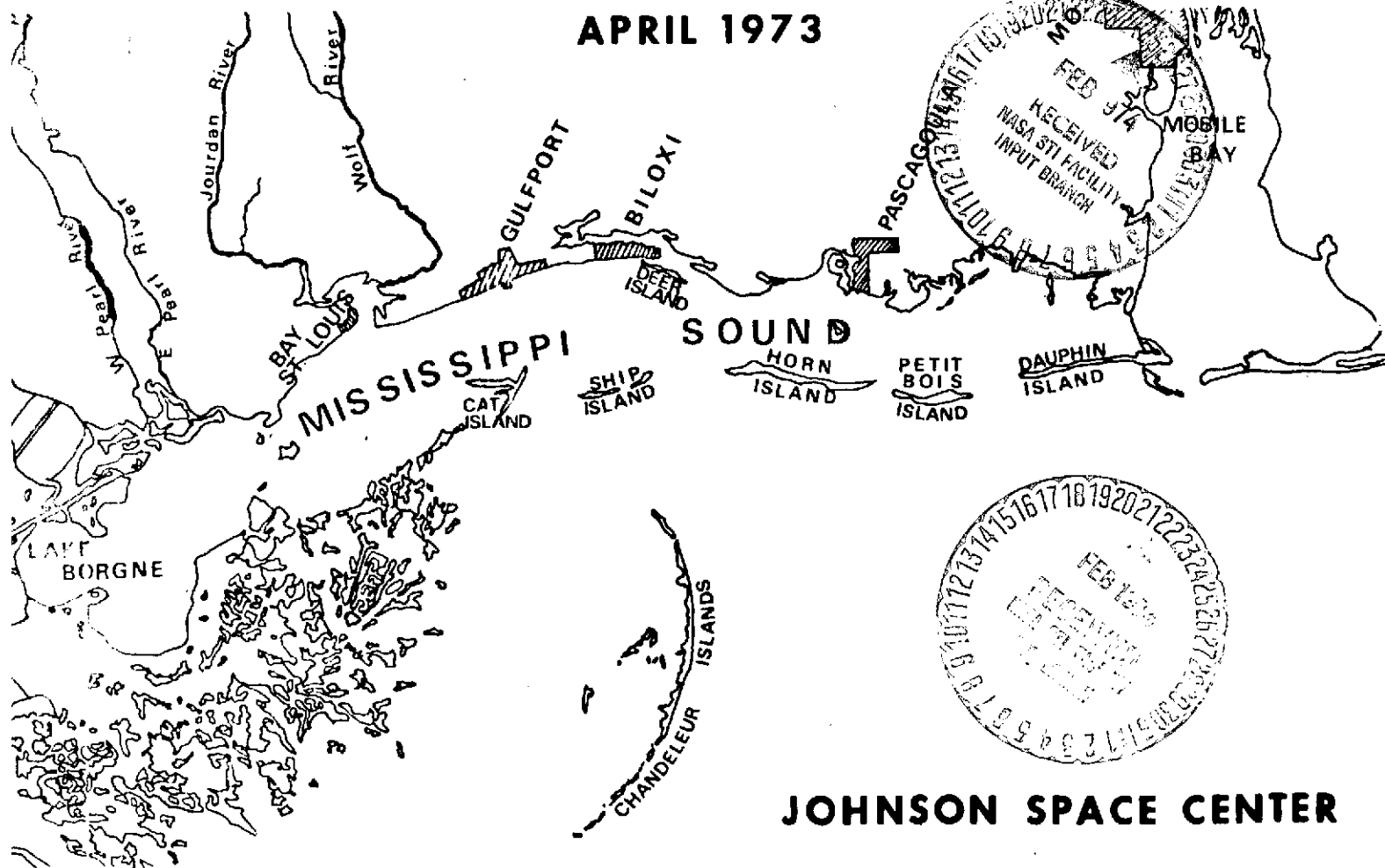
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Dr. B. H. Atwell

REPORT NO. 048

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JOHNSON SPACE CENTER

MISSISSIPPI SOUND REMOTE SENSING STUDY

B.H. Atwell

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ERL Report #048

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I, the author, assume full responsibility for any errors.

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MISSISSIPPI SOUND REMOTE SENSING STUDY

by

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I. INTRODUCTION

The Mississippi Sound Remote Sensing Study was initiated in April 1971 as part of the research program of the NASA Earth Resources Laboratory. The objective of this study is development of remote sensing techniques to study near-shore marine waters. Included within this general objective are the following: (1) evaluate existing techniques and instruments used for remote measurement of parameters of interest within these waters; (2) develop methods for interpretation of state-of-the-art remote sensing data which are most meaningful to an understanding of processes taking place within near-shore waters; (3) define hardware development requirements and/or system specifications; (4) develop a system combining data from remote and surface measurements which will most efficiently assess conditions in near-shore waters; (5) conduct projects in coordination with appropriate operating agencies to demonstrate applicability of this research to environmental and economic problems such as: the effects of fossil shell dredging and other man-made projects within the waters and adjacent marshlands on the basic biological productivity, assessing conditions related to production and harvest of fisheries resources, and other immediate problems in these estuarine areas of vital national importance.

A series of four data collection experiments were planned. These were scheduled one in each season of the year. The first two experiments took place on 22 July and 10 November 1971. This report deals primarily with the conduct and data obtained from these two experiments. However, some surface data from the third experiment are included for comparison purposes. Data collected

during the study also have been included in two separate reports dealing with the effect of the atmosphere on infrared radiative temperature measurements (Boudreau, 1972a) and salinity measurements from passive microwave radiometry (Thomann, 1972).

Technical Approach: The study was planned and has been conducted as one with primary emphasis on experimental determination of relationships between sets of remote measurements to conditions and processes taking place within a near-shore water body. Mississippi Sound was the site selected for the experiments, although the results would hopefully have general applicability. Four seasonal quasi-synoptic surface and remote measurement experiments were planned. Seasonal so that measurements would be made at times of varying water temperature, salinity, chlorophyll concentration, fresh water inflow and tidal activity, and quasi-synoptic so that circulation of the water at some instant in time could be inferred from distribution of some of the water parameters measured. These parameters generally vary between the Sound and Gulf of Mexico allowing the course of the Gulf water to be traced for some distance before assimilation with the waters of the Sound.

This plan provided for the collection of sets of remote and surface measurements obtained within a time frame so they could be compared. Thus, remote techniques for measurement of water temperature, salinity, chlorophyll content and some index of water clarity could be developed and/or evaluated. But, more than this, it provided an opportunity to combine different types of remote measurements over the entire Sound and explore the development of techniques whereby a combination of these measurements may provide information unavailable from a single set of measurements.

Remote measurements were obtained primarily from sensors aboard a NASA Earth Resources Program Aircraft (NP3A). Data were also collected using a light aircraft leased by the Earth Resources Laboratory (ERL). Surface measurements were

made and water samples collected by personnel aboard a fleet of 40 small vessels distributed throughout the Sound. Chemical, chlorophyll, suspended and total solids, metabolic activity and coliform analyses of water samples were performed in the laboratory. Parameters other than salinity, chlorophyll, suspended and total solids were not directly related to remote measurements. They were determined because some are likely to be related to parameters which could be measured remotely and because of their fundamental importance to assessing the character of the water within the Sound.

Description of the Test Area: The Mississippi Sound is a shallow elongate body of water extending from Lake Borgne on the west to Mobile Bay on the east (Figure 1). It is bounded on the north by the mainland coast of Mississippi and on the south by a series of barrier islands (from west to east - Cat, Ship, Horn Petit Bois, and Dauphin) separating the Sound from the Gulf of Mexico. The passes (from west to east - Cat Island Channel, Ship Island Pass, Dog Keys Pass, Horn Island Pass and Petit Bois Pass) between these islands connect the waters of the Sound to the Gulf of Mexico. The Sound is approximately 90 miles long and 10 miles wide with an area of 900 square miles. It has an average MHW depth of 11.6 feet; however, if the area covered by the rising tides is not considered the average MHW depth is 13.3 feet (Christmas, 1971).

The Pascagoula and Pearl Rivers are the largest rivers which flow into the Sound. They have an average discharge of 15,200 and 12,900 CFS, respectively. The Biloxi, Wolf and Jourdan Rivers along with numerous smaller streams discharge an additional 31,220 CFS of fresh water into the Sound. A part of the outflow from Mobile Bay enters the eastern portion of the Sound instead of exiting directly into the Gulf of Mexico through Dauphin Pass. This portion has been estimated to be 25% of the total outflow (Austin, 1954).

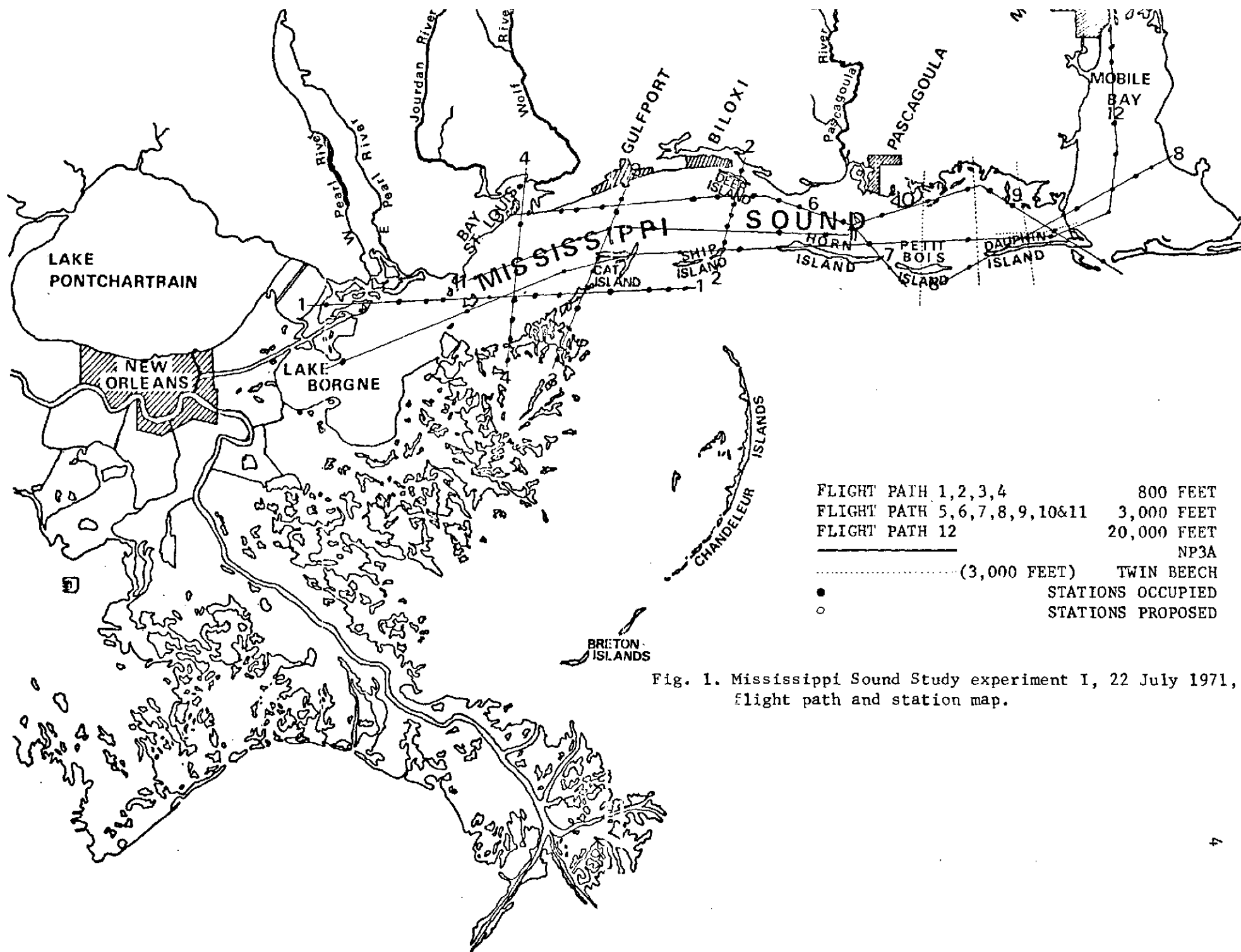


Fig. 1. Mississippi Sound Study experiment I, 22 July 1971, flight path and station map.

The classification of Mississippi Sound or any near-shore body can be considered from several points of view, and using different classification systems. An often referred to system by Pritchard (1967) defines an estuary as follows: "An estuary is a semi-enclosed body of water which has a free connection with the open sea and within which sea water is measurably diluted with fresh water derived from land drainage."

Mississippi Sound would be classified as an estuary using this rather broad definition. Pritchard goes on to develop four sub-classifications based on the geomorphological criteria. These are: (1) drowned river valleys, (2) fjord-type estuaries, (3) bar-built estuaries and (4) estuaries produced by tectonic processes. Of these four classifications, Mississippi Sound would be considered one of type (3) - a bar-built estuary. Pritchard defined a bar-built estuary as follows: "When offshore barrier sand islands and sand spits build above sea level and extend between headlands in a chain, broken by one or more inlets, bar-built estuaries are formed. The area enclosed by the barrier beaches is generally elongated parallel to the coastline. Frequently, more than one river enters into the estuary, though the total drainage area feeding a bar-built estuary is seldom large. The lower valleys of such rivers have frequently been drowned by the rising sea level, and hence, the bar-built estuary might be considered as a composite system, part being an outer embayment partially enclosed by the barrier beaches, and part being a drowned river valley or valleys. Because the inlets connecting the bar-built estuary with the ocean are usually relatively small compared to the dimensions of the Sound within the barrier, tidal action is considerably reduced in such estuaries. These systems are usually shallow, and the wind provides the important mixing mechanism. Albermarle Sound and Pamlico Sound in North Carolina are examples of bar-built estuaries." This description summarizes the geomorphological situation in Mississippi Sound.

II. DATA ACQUISITION

Surface Measurements

Purpose of Surface Measurements: The surface measurements were planned to be compatible in location and time with the remote measurements, and to provide coverage of Mississippi Sound with a station density that would allow contouring of the parameters of interest.

Eighty-five surface measurement stations (Figure 1) were selected using the following criteria: (1) along aircraft flight lines; (2) close to some easily identifiable landmark; (3) provide a reasonable areal density of observations.

In planning the first experiment, provisions were made so that boats would be on station to collect water samples and make measurements at the time of aircraft overflight. In order to satisfy this requirement and occupy all 85 stations, approximately 40 boats were required.

To lease 40 boats and crews would have been costly and difficult; therefore, we began to consider alternatives. One of these was to seek the support of educational and government institutions in the area known to have interests in Mississippi Sound.

The NASA Earth Resources Laboratory proposed to assume responsibility for coordination of all surface measurement operations, to furnish all participants with a "boat kit" containing a standard set of instruments and procedures for surface measurements (Appendix 1), to analyze water samples for salinity and chlorophyll content, and to compile and distribute all data taken. The participants were to furnish boats and crews and to gather samples and perform measurements. This proposal was well received by those groups asked to participate and formed the basis for a cooperative surface measurement activity which has operated successfully on all Mississippi Sound experiments undertaken to the present.

Pre-experiment Planning and Organization: As an example of procedures and methods used to collect surface measurement information, the Mississippi Sound I experiment is discussed. For later experiments, the methods have remained essentially the same except for changes made in an effort to make the system more efficient. These changes are mentioned in the text which follows.

During the week prior to the week for which a measurement experiment was planned, participating agencies (Table 1) were polled regarding how many vessels they would commit to the experiment. On the basis of this information, the Earth Resources Laboratory delivered to each organization a "boat kit" for each boat. Each organization designated one individual the responsibility of coordinating vessels deployed by his organization. He was briefed on the plan of the experiment by personnel of the Earth Resources Laboratory.

Mission Operation: The decision of whether or not to conduct a given experiment on the day planned was dependent on weather conditions existing on that day. This decision was made in the early morning of the day on which the experiment was planned. After a decision to proceed was reached, this information was conveyed to the participants, and they proceeded with their part in the experiment as planned.

Each surface measurement boat was to occupy a predetermined station or stations. Boats which occupied more than one station were to move to the next station after overflight by the NP3A aircraft at their first station. Boat captains were furnished instructions that advised them of location and description of stations they should occupy and the estimated time for the NP3A overflight. They were also furnished a silhouette of the NP3A to facilitate their recognition of the plane and thus realize when the overflight took place.

Laboratory Analysis of Water Samples: Water samples collected were analyzed for salinity, chlorophyll concentration, metabolic activity, coliform, pH, total solids, suspended solids and the following chemicals: chloride ion, sodium,

Table 1. Participating organizations, Mississippi Sound I Experiment
22 July 1971.

Earth Resources Laboratory (5 boats)
National Marine Fisheries Service (1 boat)
Tulane University (2 boats)
Louisiana Wildlife and Fisheries (4 boats)
New Orleans Corps of Engineers (7 boats)
Gulf Coast Research Laboratory (9 boats)
Mobile Corps of Engineers (5 boats)
Alabama Marine Science Institute (3 boats)
Food and Drug Administration (1 boat)
Alabama Department of Conservation -
 Seafoods Division (6 boats)

potassium, calcium, magnesium, iron, phosphate and nitrate. Laboratory procedures are described in Appendix 2.

Meteorological Data: Wind direction, wind velocity, and relative humidity were obtained when surface stations were occupied. In addition, radiosondes were launched from the Mississippi Test Facility Weather Station during the day of each experiment. Data obtained were used to develop atmospheric models from which corrections were developed for the remotely sensed temperature values (Boudreau, 1972b).

Tide Data: The influence of the tide on Mississippi Sound is clearly shown in both surface and remote measurements. Tide records from gauges within Mississippi Sound at the time of Experiment I (22 July 1971) and II (10 November 1971) are included in Appendix 3.

Surface Measurement Reports: All surface measurements, along with results from laboratory analysis of water samples, flight path maps, time of overflights, tide charts and meteorological data for Mississippi Sound I, II, and III experiments have been published in report form [Earth Resources Laboratory Surface Measurement Report, Mississippi Sound Study (I) 22 July 1971; (II) 10 November 1971; and (III) 26 January 1972].

Remote Measurements

Aircraft and Instrumentation: Two aircraft were used to collect remotely sensed data. The primary aircraft was the NP3A. A complete description of remote sensing systems aboard this aircraft may be found in the Johnson Space Center publication "Earth Resources Remote Sensing Systems." Briefly, however, the sensors of interest in this study, along with parameters measured with them, are: (1) Precision Radiation Thermometer (PRT-5) - measurement of water surface temperature along the aircraft flight line, (2) RS-14 infrared scanning radiometer - measurement of surface water temperature patterns, (3)

Multi-Frequency Microwave Radiometer (MFMR) - the 1.4GHz channel used to measure surface water salinity, (4) Camera systems - used for orientation of non-imaging sensors, and to study water clarity and chlorophyll content. The second aircraft, a Beechcraft leased by NASA ERL, had an instrument complement which consisted of a PRT-5 with a magnetic tape readout and a Hasselblad camera used primarily as a boresight camera for the PRT-5.

Flight Mission Planning: Flight paths planned for the Mississippi Sound Experiment I are shown in Figure 1. These were chosen to provide adequate areal coverage and be at an altitude which would permit the most favorable compromise between resolution of the sensor and maximum coverage. With these criteria in mind, three altitudes were specified.

Four flight paths (1, 2, 3 and 4) totaling approximately 124 nautical miles (223km) were flown at an altitude of 800 feet. These were chosen primarily because of the resolution of the MFMR. The antenna pattern of the 1.4GHz channel has a 3dB field of view (FOV) of approximately 15°. Thus, at 800 feet altitude ground coverage was about 200 feet. At altitudes much greater than this side lobes of the antenna beam pattern would receive an appreciable amount of energy from adjacent land masses, even though the flight path was over water. Flight paths flown at 800 feet were oriented so they would traverse areas where strong salinity variations were expected. PRT-5 data and KA-62 multiband camera photography as well as MFMR data were also collected along these flight lines. The PRT-5 data were used in analyzing microwave data and developing temperature contour maps. The photography was used to determine "actual" flight paths and in chlorophyll and sea color studies.

Another seven flight paths (5 to 11) with a total length of approximately 170 nautical miles (316km) were flown at an altitude of 3000 feet. PRT-5 data and RS-14 infrared thermal scanner imagery collected were used to construct

surface temperature contour maps of Mississippi Sound. Photography obtained was used to orient the non-imaging data and for sea color studies.

One flight path (12) was flown at an altitude of 20,000 feet. It extended from Alligator Point in the western part of Mississippi Sound to Mobile Bay in the east (108 nautical miles, 195km) and was planned primarily to obtain RS-14 thermal scanner imagery in the area of passes connecting Mississippi Sound to the Gulf of Mexico. It was expected that surface temperature anomalies associated with water masses being exchanged through these passes would be defined in this imagery, which provided coverage not only of the passes but of considerable area extending into the adjacent Sound and Gulf. Data were also collected with the PRT-5 and RC-8 aerial cameras. PRT-5 values were used in construction of a temperature contour map. RC-8 photography was used for sea color studies and to determine "actual" flight paths.

Light aircraft flight paths of the Mississippi Sound I experiment are shown in Figure 1. These flight paths, flown at 3000 feet, were chosen to obtain additional surface water temperature measurements in the eastern part of Mississippi Sound near Petit Bois Pass where coverage by the NP3A was sparse.

Flight paths for the Mississippi Sound II experiment are shown in Figure 2. The most significant change from experiment I for the NP3A flight paths was that five high altitude paths (17,500 feet) were included so that complete scanner and photographic coverage of Mississippi Sound was obtained during this and all subsequent experiments. Also, two of the low altitude paths were extended so Breton Sound and the lower Mississippi River Delta would be included in the coverage. This area was of particular interest because of studies being conducted there by Louisiana Wildlife and Fisheries Commission related to fisheries production and possible changes of environment in this region (Barrett, 1971). Remote measurements over this area are not included within this report as the

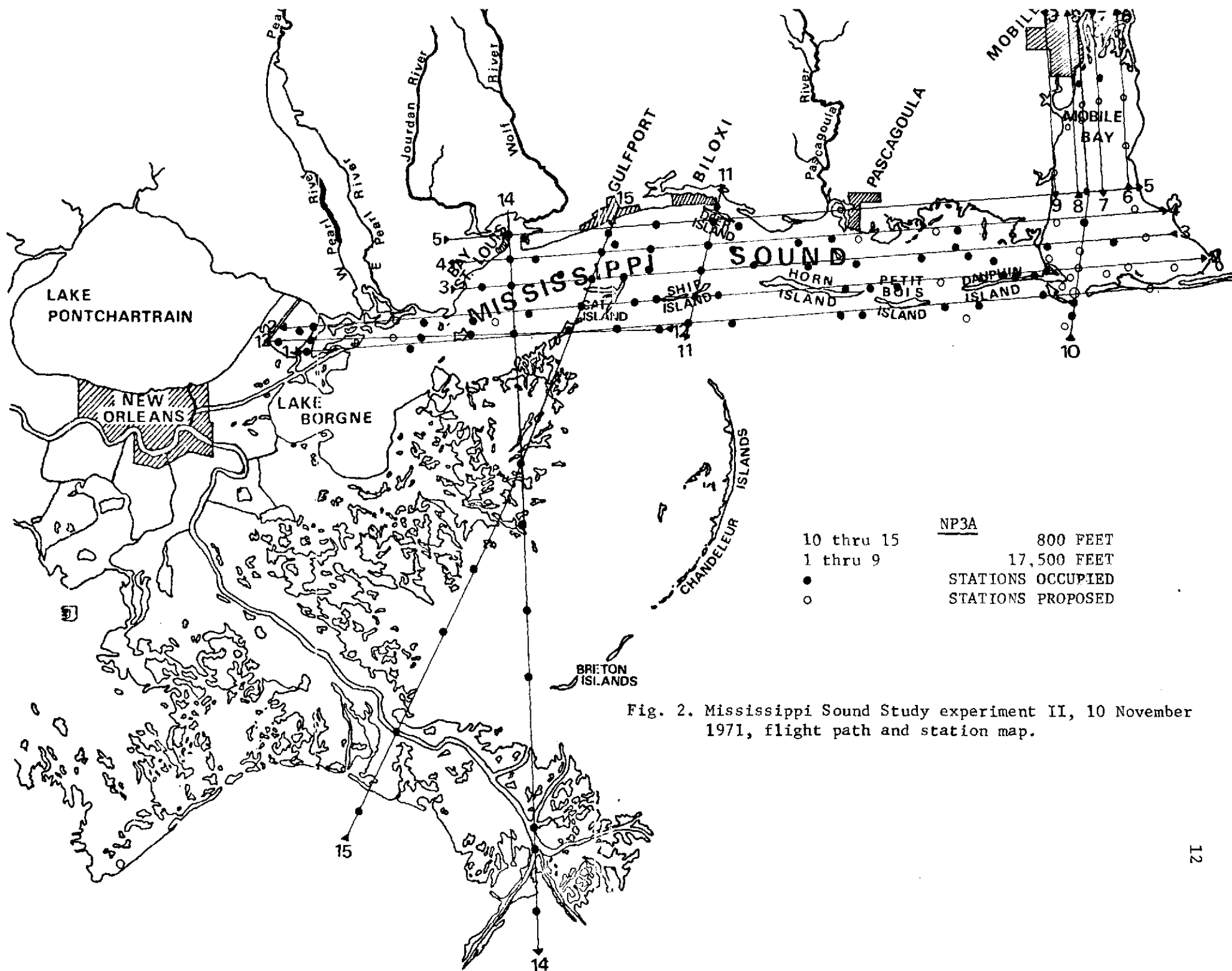


Fig. 2. Mississippi Sound Study experiment II, 10 November 1971, flight path and station map.

area was outside Mississippi Sound and showed no unique character which would make inclusion appropriate. A special report including remote and surface data was prepared for the Louisiana Wildlife and Fisheries Commission (ERL Report Number 012, 25 April 1972). All data collected by personnel aboard surface vessels are included in the surface measurement reports. An additional low altitude line extending the length of Mobile Bay was added because of the strong salinity gradient as evidenced by surface measurements in that area during the first experiment.

Flight paths for the light aircraft remained unchanged from the Mississippi Sound I experiment.

III. SURFACE MEASUREMENTS - DATA ANALYSIS

Salinity - Horizontal and Vertical Variation: The salinity regime is of fundamental importance to processes taking place within estuaries. Existing horizontal and vertical salinity fields are directly related to circulation and diffusion. Salinity variations also exert a controlling effect on the existence and distribution of flora and fauna.

Previous measurements reported by Christmas (1971) indicated waters of Mississippi Sound were subject to large spacial and temporal variations of salinity. A general trend toward higher surface salinities in the eastern part of Mississippi Sound, as compared to the western part, was observed. This was attributed to either a manifestation of Coriolis induced circulation or influx of fresh water from the Pearl River and low salinity water from Lake Pontchartrain. A large variety of vertical salinity gradients at various times and locations was reported. Higher salinity at the bottom was most commonly observed.

Surface salinity maps constructed from salinities obtained from water samples taken during the first three Mississippi Sound experiments (Figure 3) show water in the far western part of Mississippi Sound had lower salinity values than the remainder of the Sound. Nominal values of 15-25⁰/oo were found in the western part as compared to 25⁰/oo and above in the rest of the Sound during July and November experiments. In January at a time of overall low salinity, salinities of 5 to 10⁰/oo existed in the west with 10 to 20⁰/oo in most of the remainder. Also, during each of the three experiments a zone of less saline water - compared to that of the east and west - extended from the coast to Horn Island.

Absolute values of salinity were quite different at the time of the January experiment (5 to 20⁰/oo) than during the July experiment (15 to 30 + ⁰/oo). However, the salinity patterns existing during both these experiment were similar.

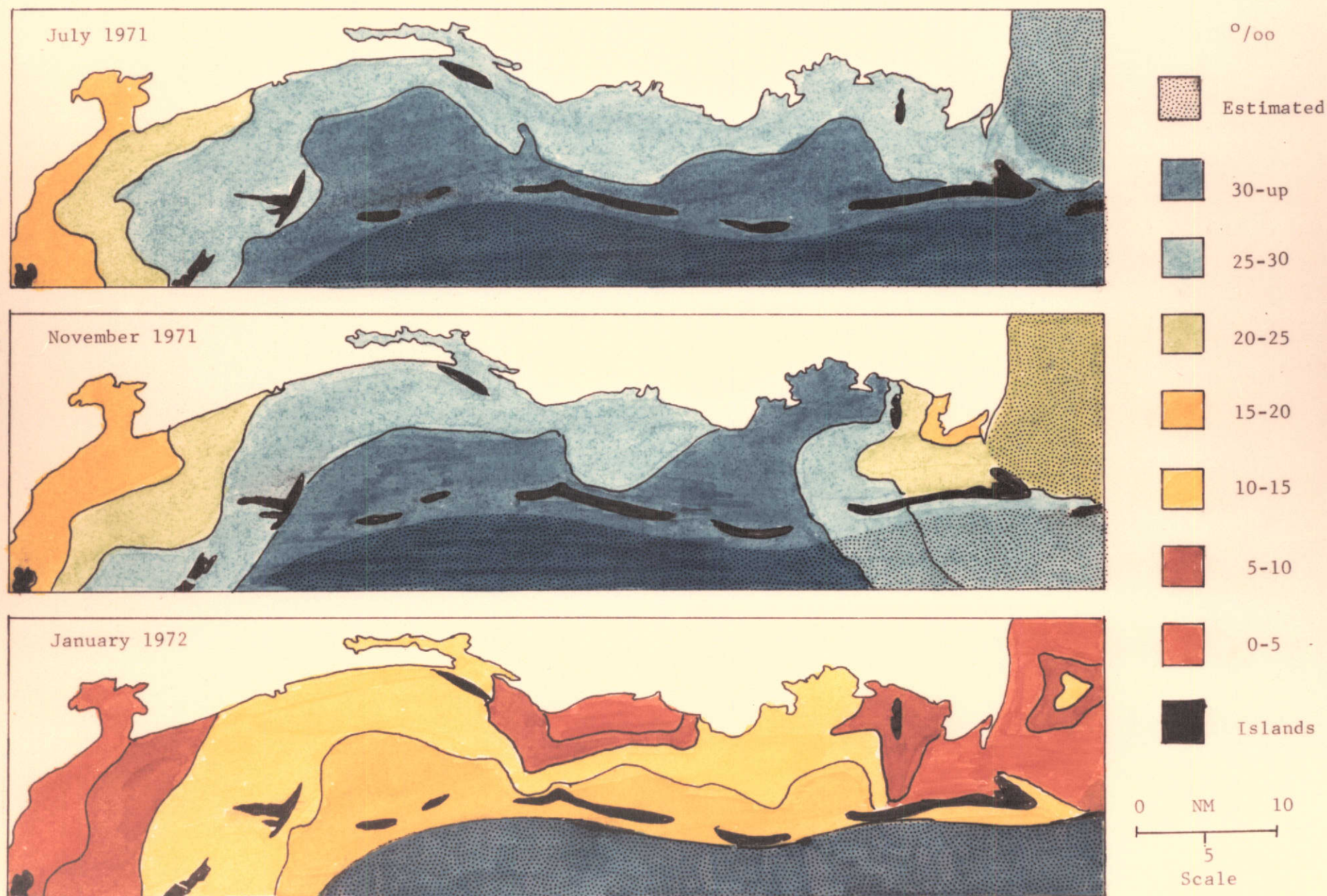


Figure 3. Mississippi Sound Study experiment I, II, III, surface salinity.

The position of the 15⁰/oo contour during January was analogous to that of the 30⁰/oo contour during July. The tide was incoming during both experiments. This is evidenced in the salinity pattern by convex "tongues" of more saline water extending coastward in the area of Petit Bois Pass and Ship Island - an effect of an influx of water from the Gulf of Mexico.

The November experiment was conducted during an outgoing tide. A strong influx of fresher water from Mobile Bay in the eastern part of the Sound was the dominant feature in the surface salinity pattern. In the western portion a convex zone of less saline water extending toward Cat Island showed the effect of the outgoing tide.

An interesting difference between July and January salinity patterns existed in the area where Mississippi Sound connects with Mobile Bay (Figure 3). The salinity pattern depicted in this area during the January experiment was different from that shown in July - both during incoming tides. January salinities were much more similar to those in November at a time of outgoing tide. This was thought due to heavy fresh water inflow into Mobile Bay. This fresh water could not enter directly into the Gulf of Mexico because of the incoming tide. Instead, this water was diverted into Mississippi Sound.

Our objective in the surface measurement phase of the Mississippi Sound study was primarily to obtain a suite of data which could be compared to remotely sensed measurements. As the remote measurement of salinity is confined to surface salinity, most of the emphasis in the salinity study was on measurements of surface salinity. However, at one station located in the western part of the Sound approximately 3 miles east of Grand Island and two miles south of the Intracoastal Waterway, measurements of salinity as a function of depth were made. These measurements obtained during the Mississippi Sound I and II experiments are presented in Figures (4) and (5), respectively.

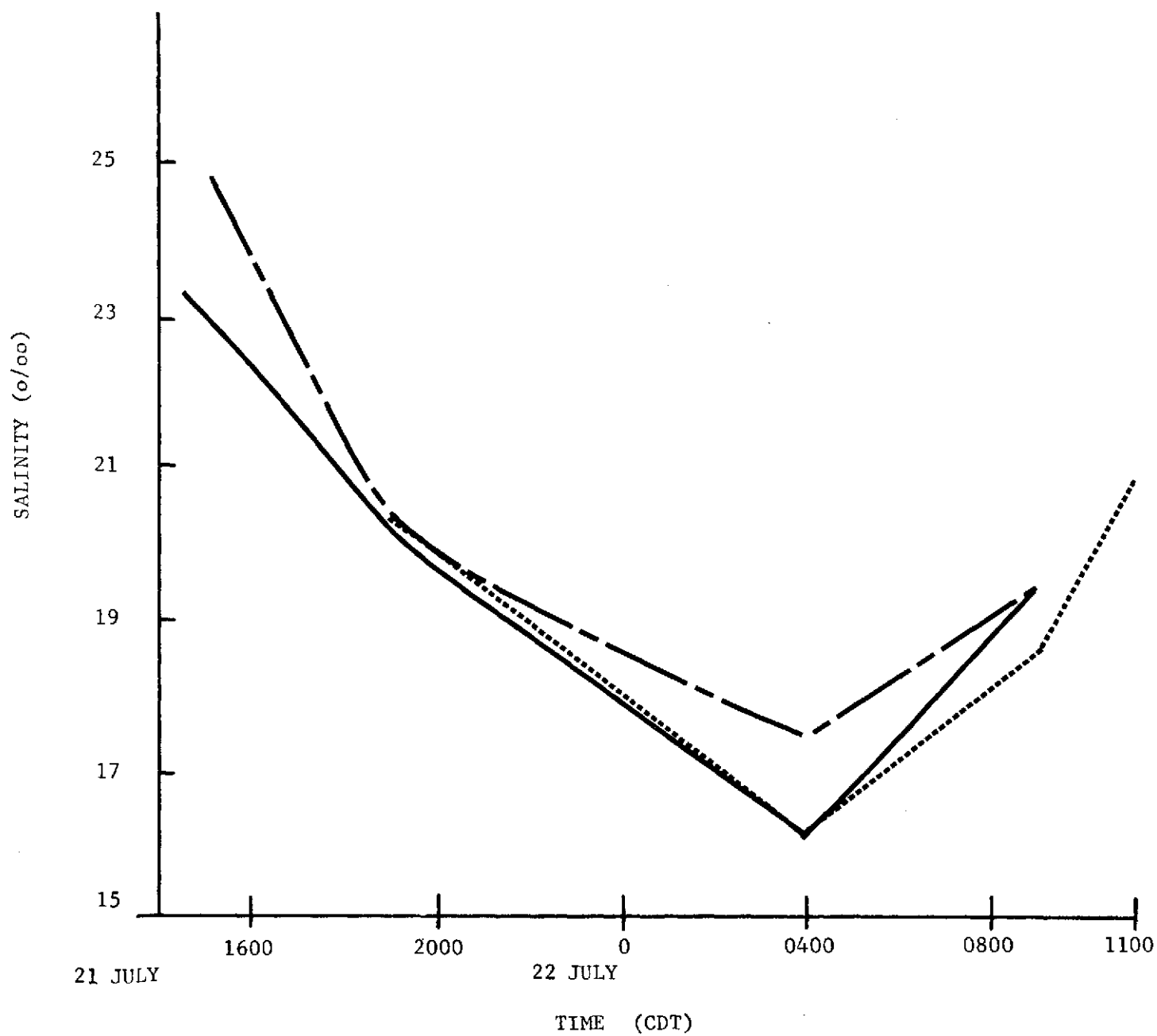


Fig. 4. Salinity as a function of depth 21, 22 July 1971, at station 7 (30°09.3'N 89°20.6'W)

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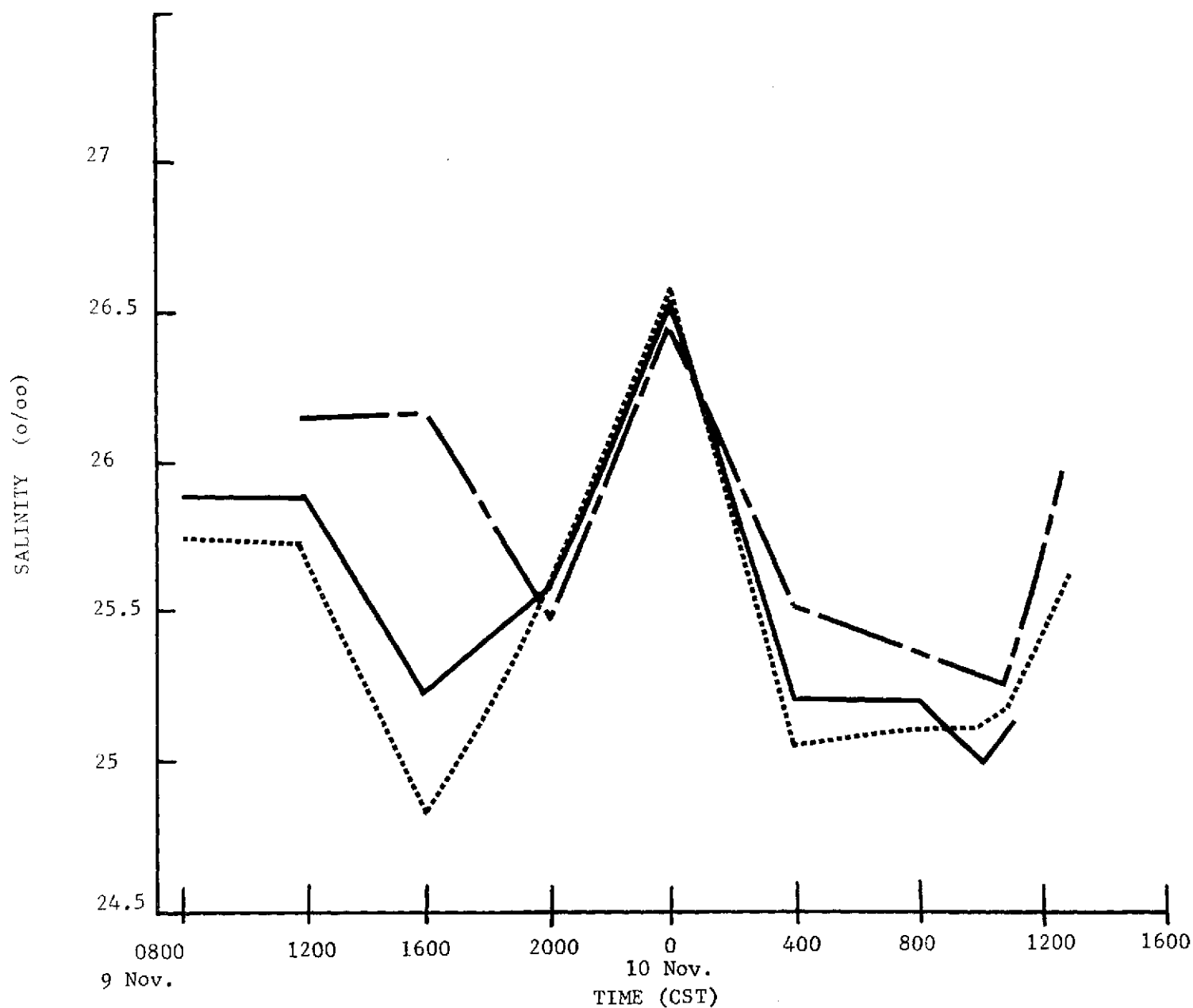


Fig. 5. Salinity as a function of depth, 9, 10 November 1971 at station 5 ($30^{\circ}09.1'N$ $89^{\circ}19.7'W$)

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The figures show in general a salinity increase with depth; however, variation between surface and bottom salinities was usually not more than about $1^{\circ}/\text{oo}$. During the July experiment salinity measurements were made over a period of approximately 18 hours, although variations as a function of depth were small there was a change of about $6^{\circ}/\text{oo}$ over the 18 hours (Figure 4). Over approximately 28 hours during the November experiment there was very little change in salinity at the surface or at depth (Figure 5).

Surface Temperature: Surface temperature maps were constructed from measurements made during Mississippi Sound I, II and III experiments (Figure 6). Surface temperatures depicted at the time of the Mississippi Sound I experiment indicated water of the Gulf of Mexico was cooler than Mississippi Sound water although the total variation in the surface water temperature in the Sound and nearby Gulf was only $2-3^{\circ}\text{C}$. Temperature variations in the area of Petit Bois Pass and the pass between Ship and Horn Islands (Dog Keys Pass) show zones of relatively cool water (less than 28°C). These are thought to be due to the Gulf water entering the Sound on the incoming tide. An area of relatively warm water (greater than 29°C) is shown north of Horn Island, the same area which showed a relatively low salinity during this period (Figure 3). These two lines of evidence point to this area as being one in which waters have restricted interchange with the Gulf. In the Sound, west of the east part of Ship Island, little temperature variation is seen.

At the time of the second experiment in November, the water temperature relation between the Gulf of Mexico and Mississippi Sound had reversed, and there was a larger contrast between the temperature of the Sound and the Gulf than was seen during the Sound I experiment. Surface water temperatures in the Gulf were greater than 25°C while almost all of the Sound was less than 18°C . The surface water temperature in the areas adjacent to Bay St. Louis and Mobile Bay were less

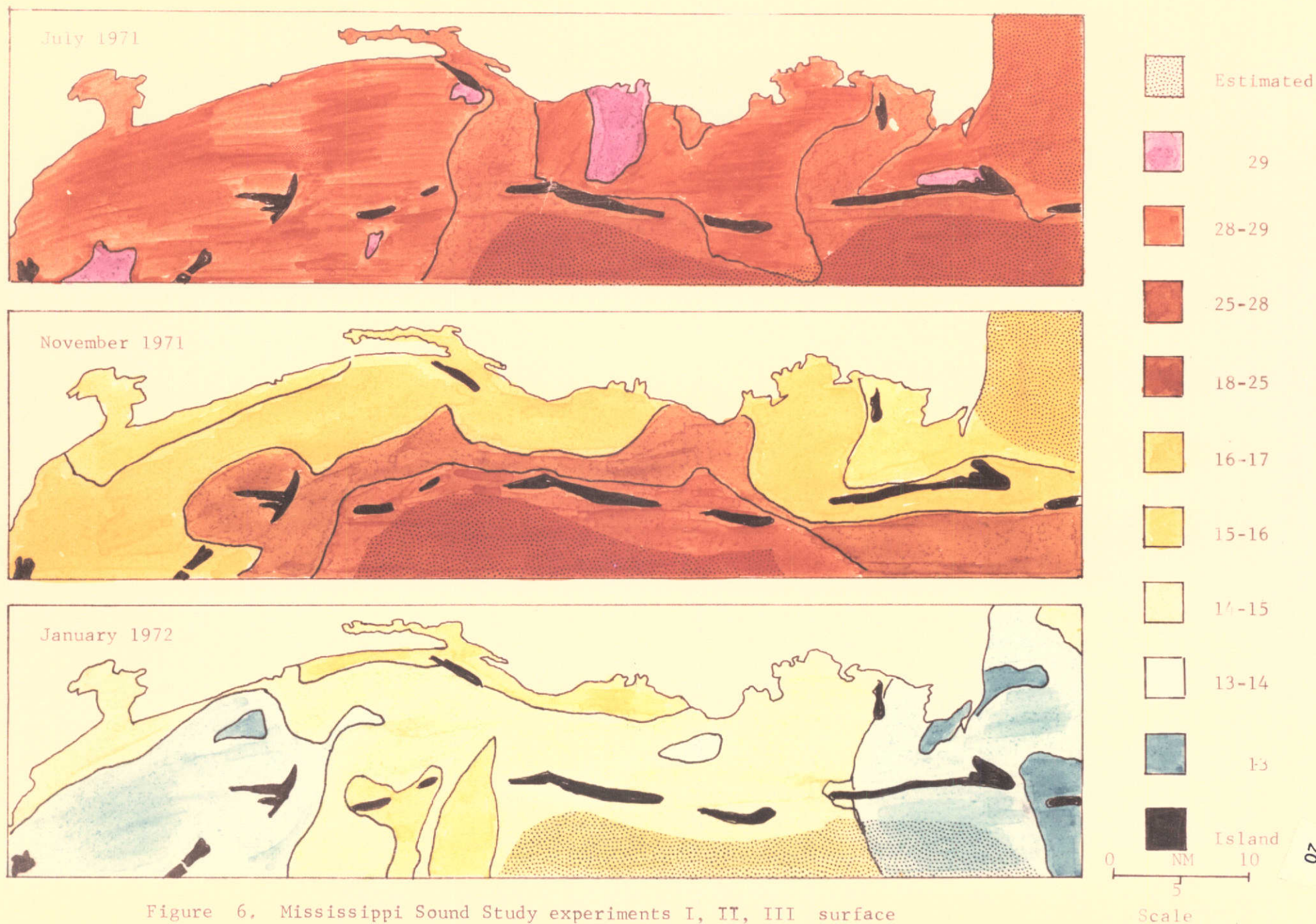


Figure 6. Mississippi Sound Study experiments I, II, III surface temperature,

than 16°C. Generally there was a regular increase in temperature from the coastline across Mississippi Sound to the Gulf of Mexico. An area of warm water (17 - 18°) extending from Horn Island Pass coastward was an interesting departure from this pattern.

In the January experiment, the large contrast in temperature between the Gulf and Sound had disappeared. The Gulf temperature, near the barrier islands, was about 15°C and the coldest in the Sound just less than 13°C. The temperature map shows water to be cooler on the east and west (less than 14°C) with warmer water between. Warm water (greater than 15°C) is shown along the coast and in the area of Biloxi Bay and Dog Keys Pass. The warmer temperature in the area of Dog Keys Pass is thought to be due to an influx of Gulf water on the incoming tide.

Surface Chlorophyll Concentration: Our main interest in surface chlorophyll concentration stems from the fact that it is thought to be an important index of biological productivity of marine waters, and considerable research has been devoted to measuring this parameter remotely.

The distribution of surface chlorophyll concentration during the three experiments is shown in Figure 7. At the time of the July experiment, a regular pattern of decreasing chlorophyll proceeding from the coastline to offshore islands and into the Gulf of Mexico was shown. The only significant departure from this description was in the areas along the coast near Bay St. Louis and to the west; near the mouth of Biloxi Bay; and along the coast in the eastern part of the Sound. In these areas lower chlorophyll content was found than along the rest of the coast.

During the November experiment surface chlorophyll distribution was different. There were four areas of water containing higher amounts of chlorophyll than the rest of the Sound. These were in the area just offshore from Gulfport, Mississippi; around Cat Island; near the mouth of the Pascagoula River and to the west;

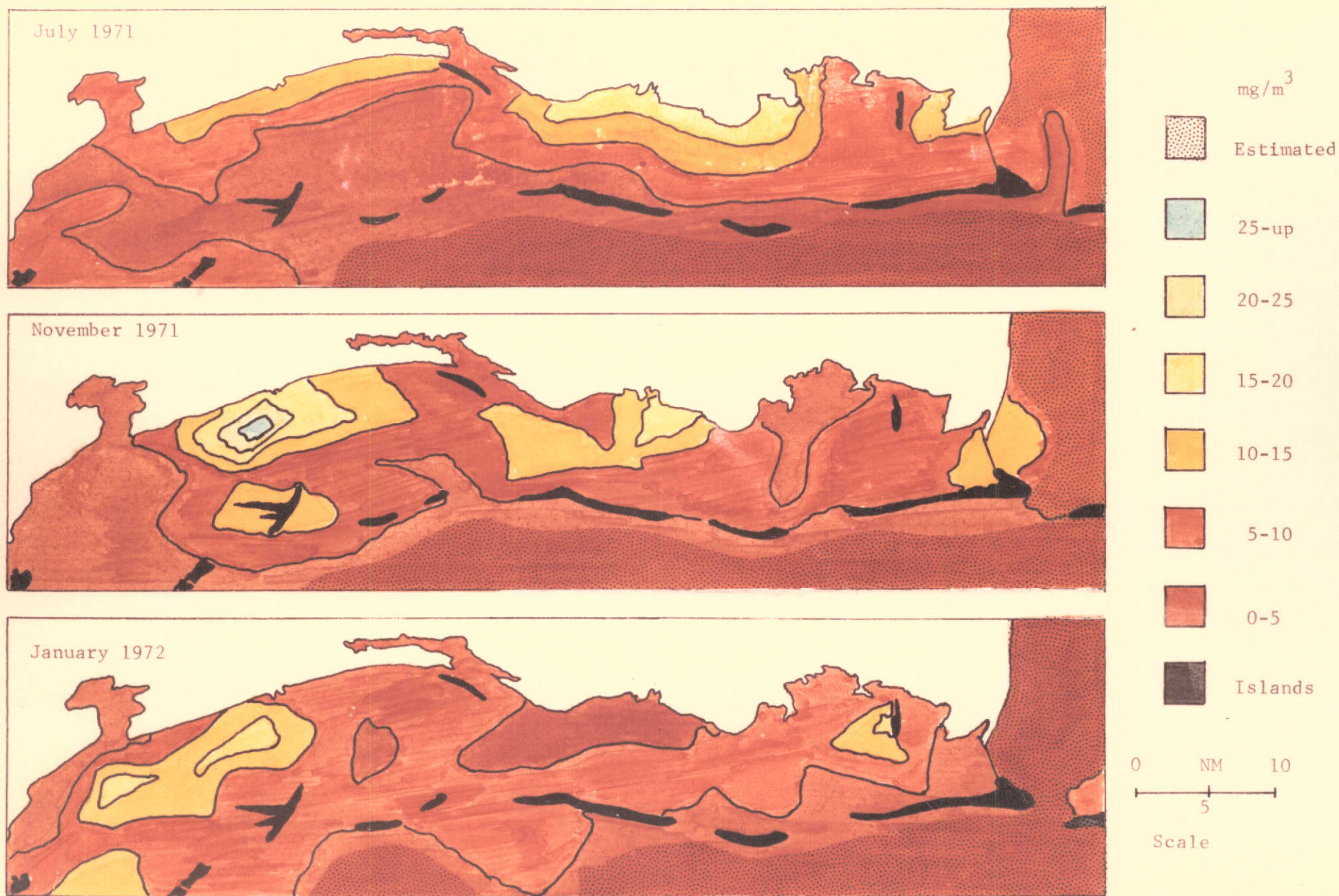


Figure 7. Mississippi Sound Study experiments I, II, III, chlorophyll content of surface water.

and the area where Mobile Bay enters the Sound. There were two areas of water with lower chlorophyll content. One was the eastern part of the Sound extending from Petit Bois Island to the coast, and the other was that portion of the Sound west of Bay St. Louis.

During the 26 January 1972 experiment, water of high chlorophyll content was found in the area extending from Gulfport to west of Bay St. Louis and in a small area in the eastern portion of the Sound. Areas of low chlorophyll were found from Bay St. Louis westward and along the coast from Biloxi Bay eastward to the Pascagoula River.

Generally the chlorophyll pattern was not as reflective of tide as that of salinity and temperature even though the Gulf water is appreciably lower in chlorophyll content than the water of the Sound.

Secchi Disk Extinction Depths: Secchi disk measurements were made at all stations. Maps were made from measurements taken during the first three experiments (Figure 8). Values ranged from less than 2.5 feet to over 10 feet. As the average depth of the Sound is only slightly greater than 10 feet, a secchi extinction depth of greater than this is usually not possible.

During all three experiments there was a trend toward decreasing secchi depths proceeding from the Gulf toward the coast. Also there was an area of clearer water within the Sound in the vicinity of Ship Island and Dog Keys Pass. In November, at a time of outgoing tide, a region of clear water (secchi depth greater than 10 feet) completely surrounded by water of less clarity is shown. From the shape of this feature and the greater than 10 foot secchi contour south of Ship Island in the Gulf, it would appear possible that this was Gulf water introduced on the previous incoming tide which had been isolated by the outgoing tide.

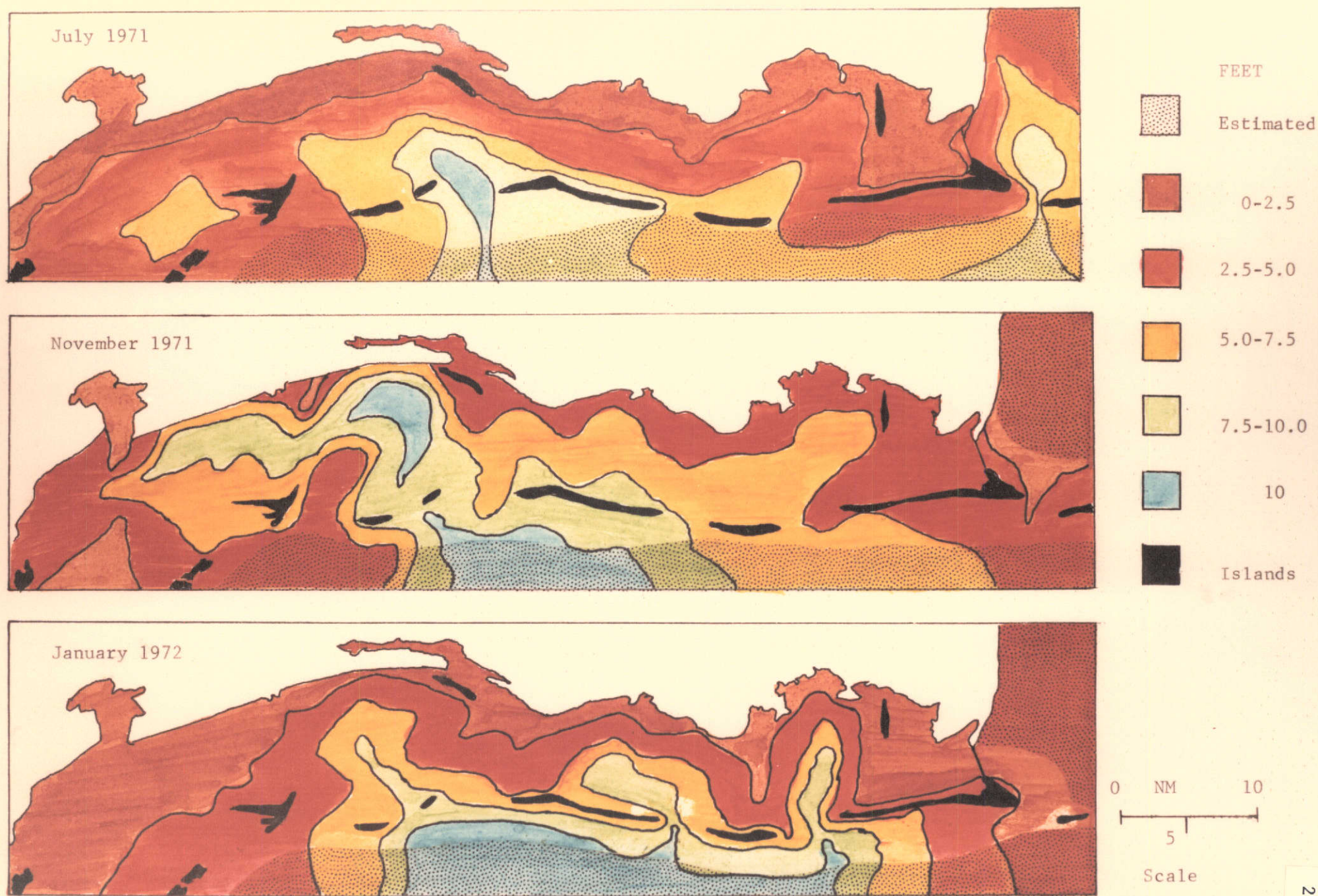


Figure 8. Mississippi Sound Study experiments I, II, III, secchi extinction depth.

In January clear water was shown in the areas of Dog Keys, Horn and Petit Bois Passes. This is thought to be Gulf water which had entered the Sound on the incoming tide.

Other Measurements: Previously discussed were four parameters of water condition - salinity, temperature, secchi extinction depth, and chlorophyll content. These were chosen for two reasons: (1) they are parameters which are of fundamental importance in characterization of near-shore marine waters, and (2) methods to measure each of these parameters remotely are either developed or are in the process of being developed.

The complete suite of surface measurements and chemical analyses of water samples obtained during the surface measurement experiments, referenced by location and time of sampling, has been published in a series of NASA Earth Resources Laboratory reports - one for each experiment (see list of References). Aside from their value in assessing the remote measurements these reports provide a set of basic information pertaining to Mississippi Sound.

IV. REMOTELY SENSED MEASUREMENTS - DATA ANALYSIS

INTRODUCTION

The previous section dealt with analysis of conventional measurements of temperature, salinity, chlorophyll content and secchi disk extinction depth. In this section analysis of sets of remotely sensed data, companion to the surface measurements, is discussed.

Radiative Measurement of Water Temperature

General Discussion: For electromagnetic energy in the far infrared region, water characteristically behaves almost as a blackbody. Energy radiated by a blackbody is a function of its temperature; therefore, it is possible to relate radiant infrared energy to temperature of a water surface. This energy may be measured with a radiometer, which need not be restricted to the vicinity of the water surface, allowing remote measurement of water temperature.

If one assumes a given infrared radiometer output expresses with fidelity radiation emitted from the sea surface, there are still sources of error which should be considered in evaluating the output of these devices. These are non-blackness of water surface and, in the case of an airborne instrument, translucence of the atmosphere.

The fundamental assumption of radiative water temperature measurement is that water behaves as a blackbody over some range of wavelengths measured. For the most part, this assumption is satisfied. There are some instance, however, where nonblackness of the water surface should be considered. Emissivity of a water surface is a function of incidence angle (Handbook of Military Infrared Technology), for angles of less than 46° it departs only about 2% from that of a blackbody, leading to a temperature error of 0.5 to 0.75°C depending on sky temperatures (personal communication, R. Boudreau). As the angle increases past 46° , however, emissivity decreases rapidly. Thus, for large incidence

angles nonblackness may introduce errors in the order of degrees C. These values are appropriate as long as only sky reflection is considered. The reflection of the sun may also cause errors. If the specular reflection of the sun in a plane water surface were to fill the field of view of the radiometer, this could cause an error as great as 100°C even at normal incidence (Saunders, 1967). Although theoretically alarming, in practice the reflection of the sun is not usually considered significant because of sea surface roughness and the limited area effected.

The second and generally much more pronounced source of error is change in radiation as it is transmitted through the intervening atmosphere. Gases in the atmosphere absorb and re-emit radiant energy at their own temperature, different from that of the water. Because of this, energy emitted from the water surface may be altered considerably before reaching the radiometer.

There are two regions in the infrared spectrum, 4.5 to 5.5 μ and 8 to 14 μ , in which the atmosphere is relatively transparent. By restricting measurements to these wavelength ranges, effect of the atmosphere is minimized. It is usually, nevertheless, appreciable. An error of 1°C for a flight altitude of 1000' is a typical value. Methods are available which allow effects of the atmosphere to be estimated, allowing an atmospheric correction to be applied to the data. The magnitude and sign of this correction is dependent on temperature and composition (primarily H₂O and CO₂) of the atmosphere.

One way to determine the effect of the atmosphere as well as nonblackness is to compare airborne and surface measurements over the same water surface at the same time. It is possible, in this way, to correct the rest of the airborne measurements by including this determined effect of the atmosphere. This procedure was used to reduce PRT-5 measurements taken during the Mississippi Sound I and II experiments. It has the obvious disadvantage of requiring a surface measurement.

If the vertical distributions of water vapor, carbon dioxide and temperature are known it is possible to construct an atmospheric model which will allow prediction of the effect of the atmosphere on upwelling radiation. This method does require a sounding of the atmosphere and is subject to some error because no atmospheric model available at this time takes into account aerosols which may have a significant effect (Boudreau, 1972b). Atmospheric corrections determined by Boudreau using an atmospheric model and those determined by comparison with surface measurements for Mississippi Sound experiments I and II are listed in Table 2.

During both experiments, there was poor agreement between values obtained by the two methods at 800 feet. The values obtained from comparison to surface measurements are 2.0°C and 2.3°C for experiments I and II respectively; whereas, the correction predicted by the model was 0.3°C and 0.1°C . A likely hypothesis explaining this disparity is that at low altitude, the aerosols which are not included in the model, exert a disproportional influence on the transmission of the infrared radiation.

At high altitudes, 20,000 feet for Mississippi Sound I and 17,500 feet for II, there was better agreement between the two methods. This was particularly true during experiment II which occurred in November. This was thought due to the different types of air mass existing in the area at the times of the experiment - warm and moist during experiment I and cool and dry during experiment II (Boudreau, personal communication).

An interesting method to correct for atmospheric effect and nonblackness of the water surface was reported by Saunders (1967). This method required normal and oblique measurements of radiation from the water surface. Boudreau (1972a) discussed this technique in the context of atmospheric correction to infrared scanner data. However, it was not used in reduction of data presented in this report.

TABLE 2. Atmospheric Corrections.

MISSION AND ALTITUDE	COMPARISON TO SURFACE MEASUREMENTS	ATMOSPHERIC MODEL (FROM BOUDREAU)
Mississippi Sound I		
800'	2.0	0.3
3000'	3.2	2.0
20000'	6.0	9.3
Mississippi Sound II		
800'	2.3	0.1
17500'	4.0	4.3

In comparing radiative and "bucket" measurements of sea surface temperature there exists still another reason for disagreement between the two methods. For radiation of infrared wavelengths, water is opaque in thicknesses of 0.02mm (McAlister, 1964); thus, radiative temperature measurements of water reflect the temperature of a surface film with approximately this thickness. A "bucket" temperature, in contrast, would be representative of an average of the upper few inches. Moreover, the upper few millimeters of the sea surface is a zone in which exchange of heat between the water and the atmosphere takes place. This leads to temperature gradients in the upper few millimeters and temperatures which are not representative of the water below.

Previous comparison of airborne radiometric and "bucket" temperatures (Saunders, 1967) showed radiometric values, after correction for atmospheric effects, to be 0.2°C to 0.35°C cooler. Ewing and McAlister (1960) reported radiometric temperatures some 0.6°C below those measured with a thermister a few mm below the surface of the water. Boudreau (1964) reported similar findings from measurements made in the Gulf of Mexico.

Finally, the question of the effect of sea surface roughness on radiometric temperature arises. Saunders (1967), in an analysis based on the work of Cox and Munk (1954), determined that for normal viewing average irradiance is practically independent of roughness.

Mississippi Sound I: Data were collected with PRT-5's aboard the NP3A and the ERL light aircraft. Design of the experiment called for these data to be reduced to some common datum and all data used to develop a quasi-synoptic, surface-water temperature contour map. Two corrections were made to the data before construction of the temperature map (Figure 9): (1) correction for water temperature increase over the measurement period, (2) atmospheric correction.

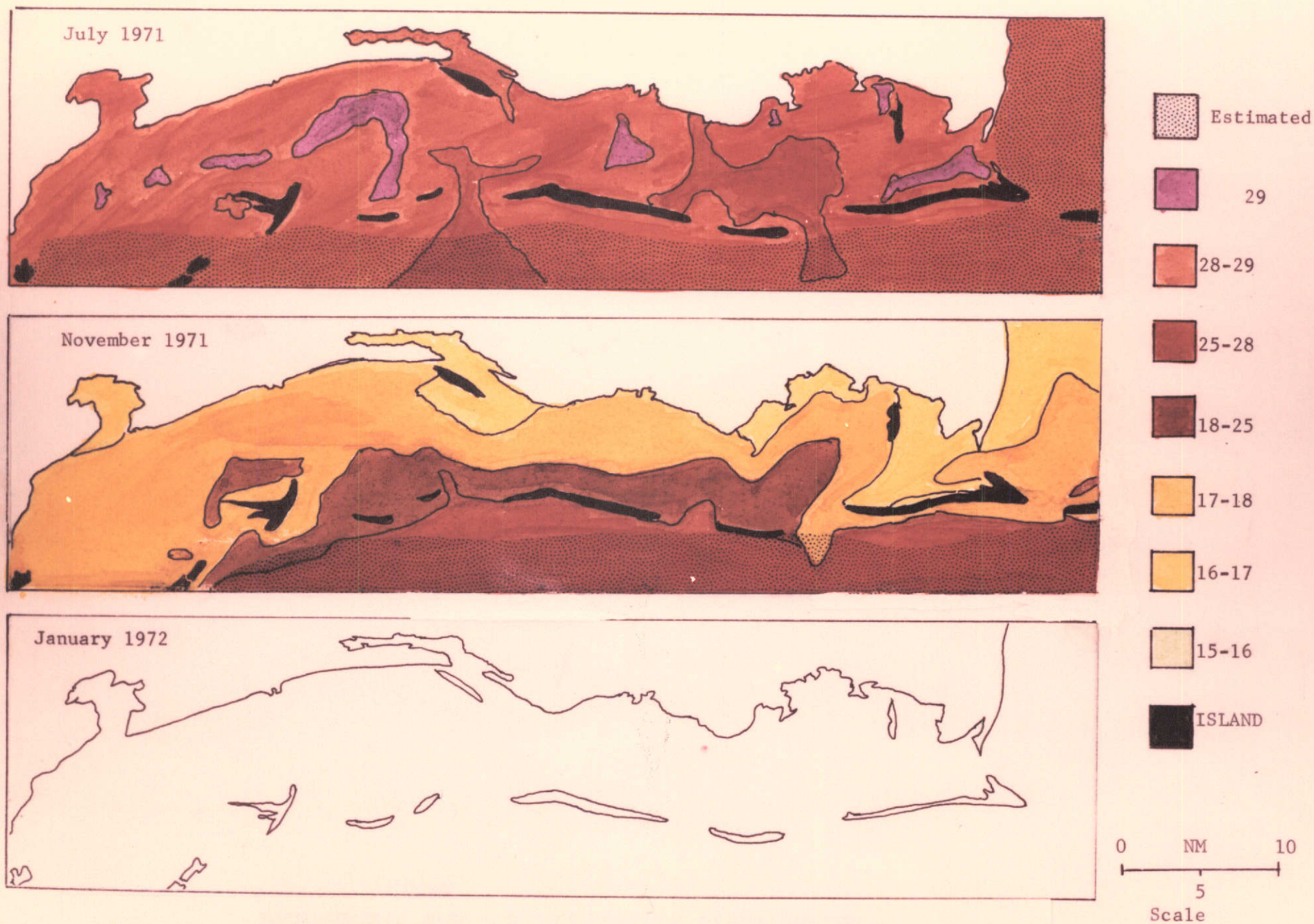


Figure 9. Mississippi Sound Study experiments I, II radiometric temperature.

As temperature measurements were made from 9 a.m. to 1 p.m., surface water temperature would increase over this period due to heating by the sun. In order to assess the magnitude of this effect, a correction which would allow all temperatures to be referred to a single point in time was calculated. Surface temperatures recorded at 21 stations located in the central part of the Sound, where temperature would be little influenced by tidal flow, were plotted as a function of time. A best fit straight line was drawn through these points, and all temperatures were corrected to 10 a.m. On the basis of this analysis, corrections ranging from 0.3°C to 0.7°C were determined.

Atmospheric corrections for PRT-5 data collected from the NP3A at both 800 and 3000 feet were determined in the following manner. Differences between water temperatures measured with mercury thermometers aboard surface vessels and those measured by airborne PRT-5's at approximately the same location and time were calculated. The average difference between these values at 19 stations along the 3000 feet altitude flight paths was 3.2°C . An average was used in hopes that this would improve the accuracy of the correction; however, the correction could have been determined from one boat. Similarly, for data collected at 800 feet, a correction of 2°C was determined from an average of differences at 21 stations. A problem arose in combining the PRT-5 data from the light aircraft with that obtained from the PRT-5 aboard the NP3A. A comparison showed a disagreement of approximately 1°C . As there had been no common pre-experiment calibration of the instruments, it was impossible to say which instrument was in error. The bulk of the measurements were from the NP3A; therefore, an arbitrary correction was made to data from the light aircraft to make these compatible with values from the NP3A PRT-5.

These corrected data along with additional qualitative information obtained from the RS-14 infrared scanner were used to construct a temperature map (Figure 9a). A comparison of this map with the one drawn from "bucket" temperatures

(Figure 6a) shows that both maps indicate similar temperature patterns. Both show areas of very warm water ($>29^{\circ}\text{C}$) north of Dauphin and Ship Islands and cooler water in the Petit Bois Pass area. The map drawn from PRT-5 data shows some areas of water with temperatures greater than 29°C in the western part of the Sound which do not appear on the map drawn from "bucket" temperature. This was thought due to greater measurement density afforded by the airborne measurements.

Mississippi Sound II: Data were obtained from the PRT-5's aboard the NP3A and ERL light aircraft as in the Mississippi Sound I experiment. Analysis was essentially the same, with the same data corrections being made in order to construct a synoptic surface temperature map (Figure 9b).

A comparison of the temperature map constructed from surface measurements (Figure 6b) to the corrected radiometric map (Figure 9b) shows good agreement. The two maps are more similar than maps drawn by the two methods were for the Mississippi Sound I experiment in July. A possible explanation for better agreement is that the radiometric measurements were more representative of "bucket" temperature in November than July. The basis of this hypothesis is that in July as heating takes place at the water surface, the water becomes less dense (neglecting an increase in salinity due to evaporation) thereby forming a thin layer of warmer water at the surface. Conversely, in November, cooling causes the water to become more dense and sink from the surface and to be replaced by warmer, less dense water from below. This would result in well mixed water in which surface radiometric temperature and "bucket" temperature are in good agreement.

RS-14 Infrared Scanner

Calibration Data: The scan mirror of the RS-14 views on each complete revolution two internal blackbodies (calibration sources) with known temperature. The response to these as well as the scene is recorded. By comparing the output

of the system as it views each of the blackbodies with the output from a water scene it is possible, theoretically at least, to relate temperature of the scene to a thermometric scale. Two forms of data output are available from the RS-14: (1) film imagery, (2) analog magnetic tape recording of output voltage. Both will be considered in the following analysis.

A calibration analysis of a portion of the RS-14 scanner data collected during the Mississippi Sound I was performed (Eppler et. al. 1972). Data used were collected from an altitude of 20,000 feet over an area near the west tip of Dauphin Island. The scanner imagery of this area showed a distinct water temperature variation between cooler water entering the Sound from the Gulf of Mexico on the incoming tide and resident Mississippi Sound water (Figure 10).

The objective of the analysis was to determine from the scanner data the difference in temperature between the two water masses. Variations shown along lines A and B (Figure 10) were analyzed. A microdensitometer scan of imagery coincident with these two lines showed a variation in density between the "hot" and "cold" water of 0.04 and 0.06 density-units along A and B, respectively.

Film densities were determined for response to the blackbody calibration sources, and a density-to-temperature conversion curve was derived. From this a water temperature of 15.5°C was determined for water along A just outside of the distinctive cold water pattern. This temperature was quite different from the 22°C measured by the PRT-5 for the same area. The large error was attributed to different conditions under which ground scene and calibration source imagery were recorded.

In an effort to avoid some of the errors introduced in the film recording, output recorded on magnetic tapes was analyzed. A single scan line, which included response to the scene as well as calibration sources, was displayed on an oscilloscope trace (Figure 11). A linear scale between hot and cold

Mississippi Sound Study experiment I.

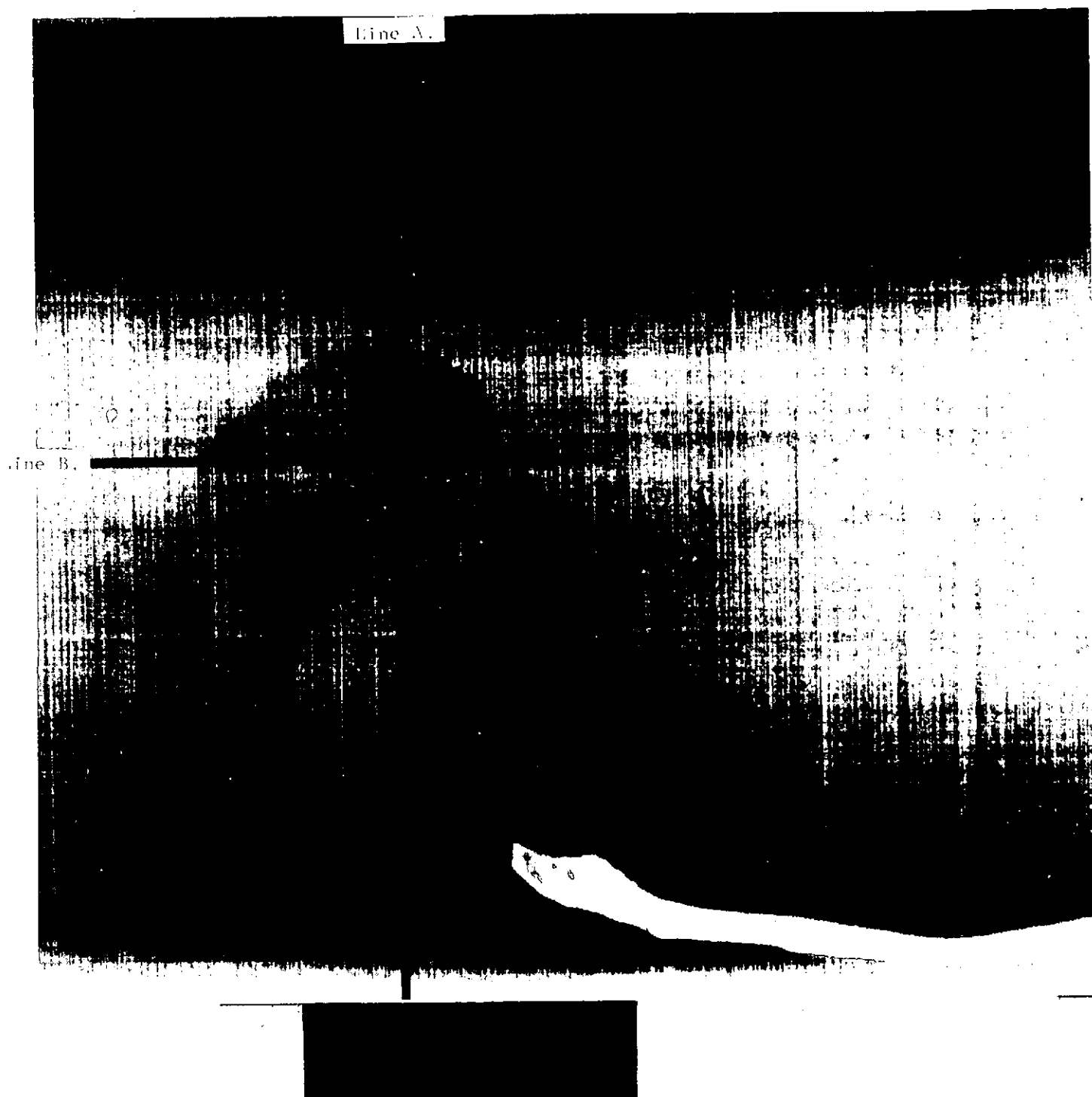


Fig. 10. Mississippi Sound Study experiment I, 22 July 1971.
RS-14 infrared imagery, Petit Bois - Dauphin Island area,
altitude 20,000 feet.

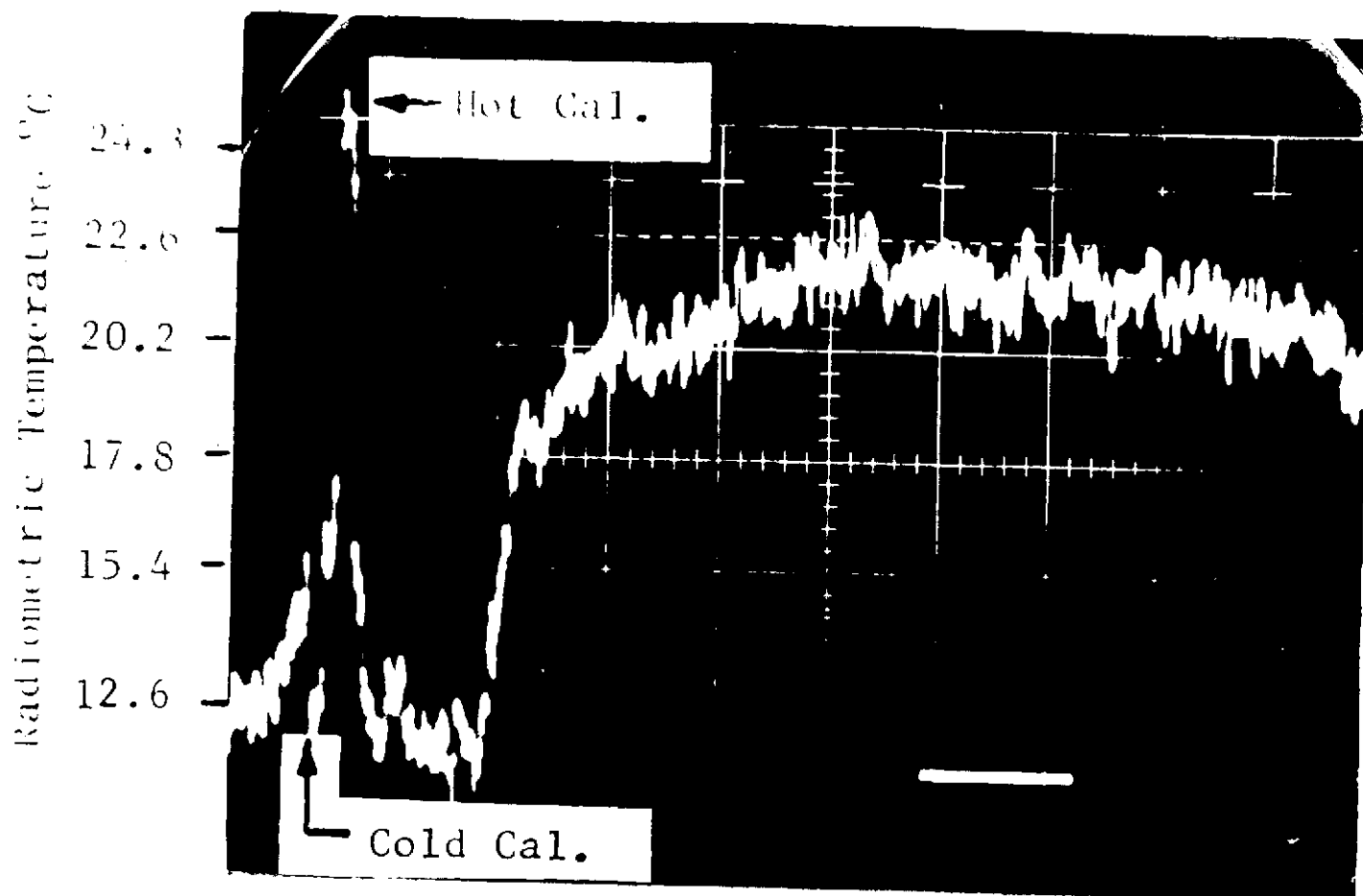


Fig. 11. Oscilloscope display of single scan line from RS-14 scanner (Eppler et al., 1972).

calibration sources was established. From this a temperature of 22°C , the same value obtained from the PRT-5, was determined for water along line A. Although this analysis yielded a temperature for the overall scene which agreed well with PRT-5 data and surface measurements, there was no discernable manifestation of temperature difference in the water as shown in the scanner imagery. In the imagery there is an overlap of successive scan lines resulting in an effective scan line averaging. Thus, detector and other system noise is reduced in the imagery as compared to viewing a single trace, making possible the display in the imagery of subtle temperature changes.

It would have been possible to assign a temperature difference between the two different water masses on the basis of density-to-temperature conversion determined directly from the film imagery. However, because of poor agreement between the temperature obtained and the temperature recorded by the PRT-5, another approach was used. This was based on calibration of the film imagery using targets within the scene, in this case Dauphin Island and adjacent waters. The apparent temperature of these targets was established from video signals recorded on magnetic tape. Densitometer measurements of imagery showing island and water were related to these temperatures. From this analysis a density-to-temperature relationship of 10°C per unit change in film density was determined. Thus, at 0.04 to 0.06 density difference between the two water masses corresponded to a temperature difference of 0.4 to 0.6°C , a value which is in agreement with data obtained from surface measurements and PRT-5 from the ERL light aircraft (Figure 12).

Imagery - Mississippi Sound I: The RS-14 infrared scanner was operated along flight paths 5 - 11 at 3000 feet altitude and path 12 at 20,000 feet. Flight path 12, an east-west trending line planned to provide coverage of areas adjacent to the passes connecting Mississippi Sound to the Gulf of Mexico, proved to be

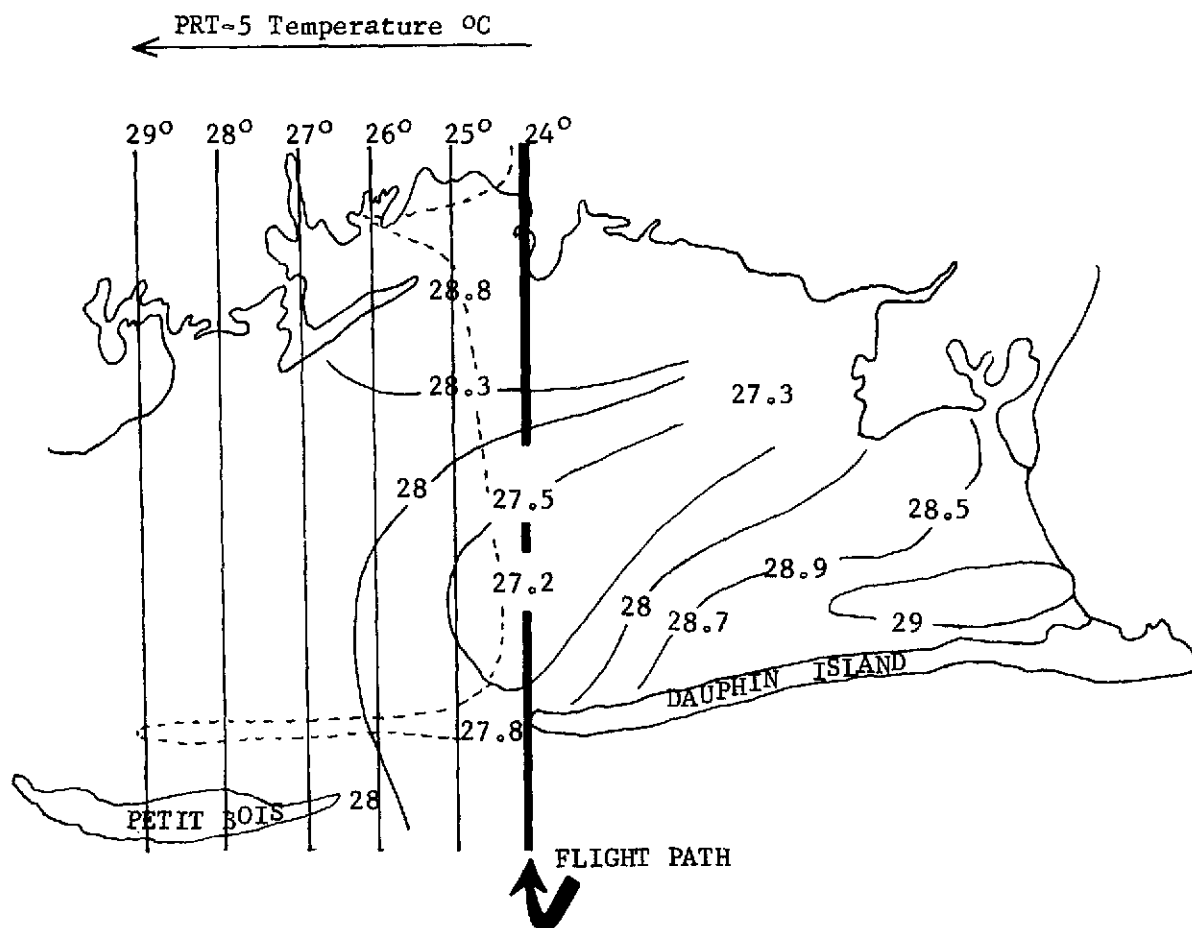


Fig. 12. Mississippi Sound Study experiment I, 22 July 1971. Light Aircraft PRT-5 temperatures and temperatures measured by surface vessels - Petit Bois Pass area.

the most interesting. Imagery from this line (Figure 13) shows surface temperature anomalies associated with the influx of cooler Gulf of Mexico water into the Mississippi Sound. This imagery also indicates that the western part of Mississippi Sound had generally a more uniform surface temperature than the rest of Mississippi Sound, consistent with the pattern depicted by the maps drawn from surface measurements.

A section of scanner imagery from line 12 showing the Petit Bois Pass region (Figure 10) was of particular interest because of sharpness and detail shown by the temperature anomaly in that region. This anomaly displayed the course of Gulf of Mexico water after it entered Mississippi Sound. Discussed previously was a calibration analysis of scanner imagery which yielded a value of 0.4 to 0.6°C difference between the Gulf of Mexico water, which had entered through Petit Bois Pass on the flood tide, and surrounding Mississippi Sound water.

This section of imagery was collected between 11:51 a.m. and 11:52 a.m. on 22 July 1971, the day of the experiment. The tide record for Dauphin Island on that day (Appendix 3) indicated high tide occurred at 10 a.m. Thus, the time of overflight occurred at the end of a period during which there had been a strong influx of Gulf of Mexico water. From the scanner imagery it appears as though a continuous influx of cooler water entered through the pass and was deflected until the leading edge of the cool water mass was directed almost due south again. This "tongue" of cool water extended approximately 3 miles north of Petit Bois Pass.

The winds in this area as reported by the surface measurement vessels were out of the N-NE at 5-15 knots from 9 a.m. until the time of the overflight. This could account for the recurvate shape of the cool water. The gentle deflection to the right shown in the southwestern portion of the "tongue" is suggestive of the Coriolis effect. If this were the case, it could be an indication of the influence of the Coriolis effect on the general circulation in Mississippi Sound.

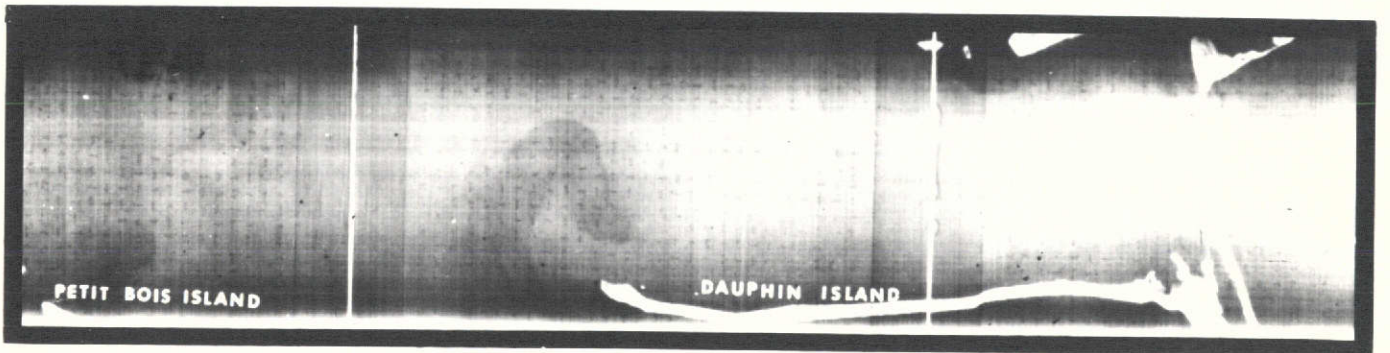
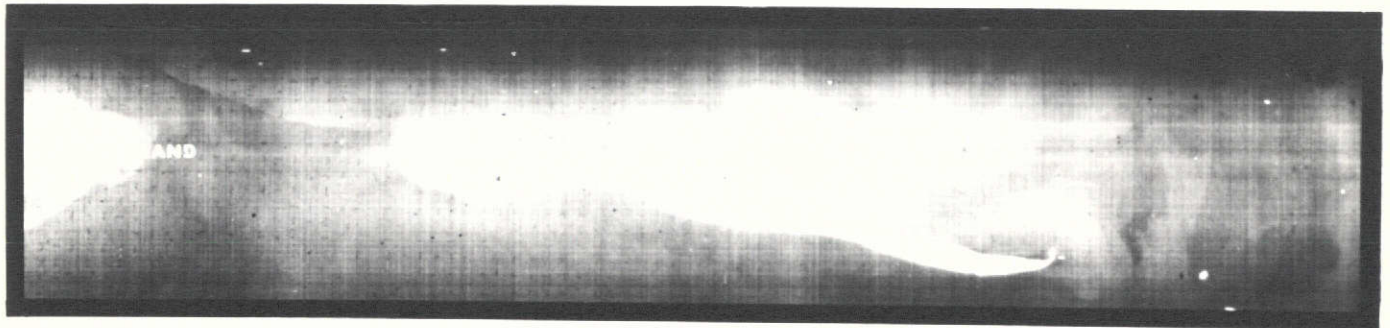
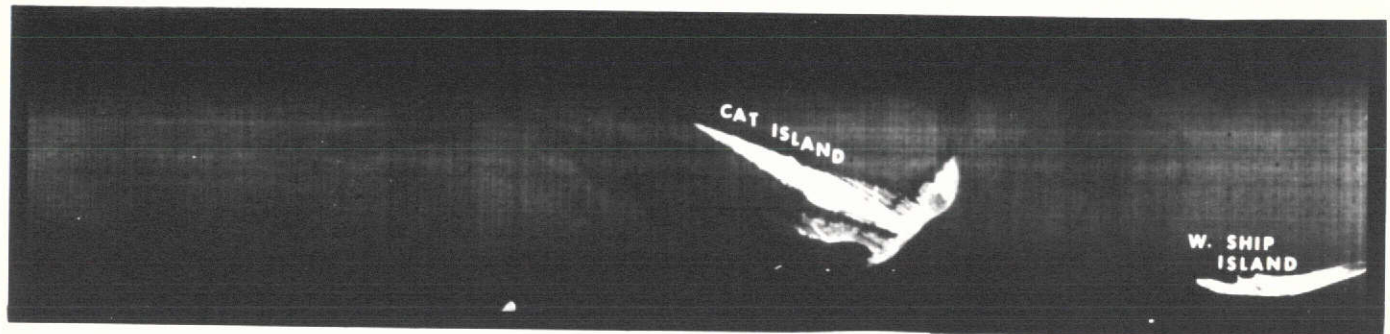
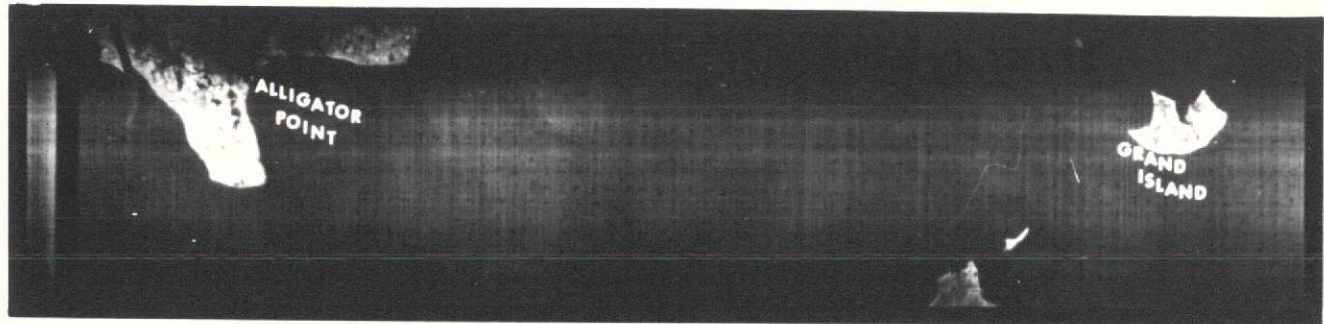


Fig. 13. Mississippi Sound Study experiment I, 22 July 1971. BS-14 infrared imagery flight path 12 from Alligator Point (west) to Mobile Bay (east), altitude 20,000 feet.

Mississippi Sound II: A strip mosaic (Figure 14) of Mississippi Sound from west of Ship Island to Mobile Bay was constructed with RS-14 imagery from flight paths 1-5 collected at an altitude of 17,500 feet. These data were collected from 12:39 p.m. to 14:27 p.m. local time on 10 November 1971, the day of the experiment. Lighter tones in this imagery indicate warmer water temperatures.

During the second experiment in November surface measurements indicated water in the Gulf of Mexico was warmer than that of Mississippi Sound. This was in contrast to the situation which existed in July. The scanner imagery reflected this, showing Gulf of Mexico water to be uniformly warmer.

The tide record for Biloxi Bay, Mississippi and Dauphin Island, Alabama (Appendix 4) indicated the tide at the time of overflight was at the end of an ebb period. Effects of the tide are manifested in the mosaic, particularly in the eastern part of the Sound. A mass of cooler water is shown extending from Mobile Bay along the north side of Dauphin Island and on through Petit Bois Pass into the Gulf. This is a result of the Mobile Bay outflow during the ebb tide. An area of warmer water extending north of Petit Bois Island toward the coast and west of Horn Island may be remnant of Gulf of Mexico water which had been introduced into the Sound during the previous flood tide.

The imagery of the western part of Mississippi Sound shows surface temperature in this area to be much more uniform than in the eastern Sound. Also, it appears that the outflow of Mississippi Sound water through the passes to the west was not equivalent to the outflow from Petit Bois Pass.

Photographic Data

Orientation of Non-Imaging Sensors - NASA NP3A: Two non-imaging sensors of primary importance were used in this study. These were the PRT-5 and MFMR. Relating response from these sensors to a given "surface scene" was accomplished

MISSISSIPPI SOUND STUDY

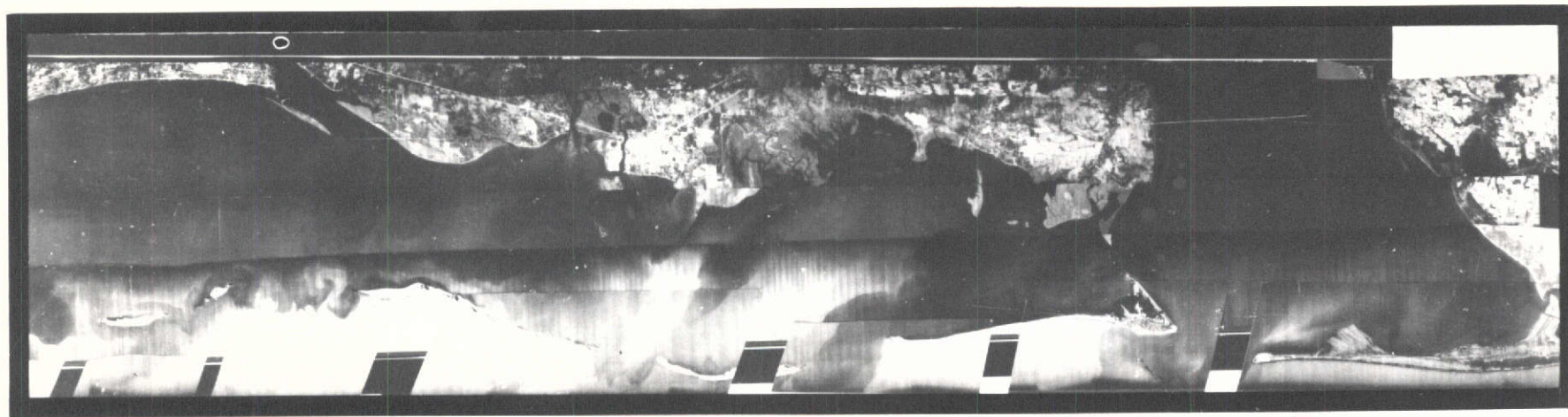


Fig. 14. Mississippi Sound Study experiment II, 10 November 1971,
mosaic of RS-14 infrared scanner imagery, altitude 17,500 feet.

by plotting an actual flight path using frames of photography from RC-8 and KA-62 cameras. Areas shown in specified frames of photography were outlined on 1 to 80,000 scale C. and G.S. charts of Mississippi Sound. Frames including land scenes were located by reference to land features shown on these charts and frames over water by a linear interpolation between land marks. The time reference included on these frames was used to relate surface scenes to time which in turn could be related to time referenced response of the PRT-5 and MFMR. Although a considerable portion of flight paths of the aircraft was over water, there was enough land in the photography to make this a practical way to orient data.

Chlorophyll Studies: One of the objectives of the Mississippi Sound study is to develop a technique to remotely determine phytoplankton concentration of near-shore marine waters. In this phase of the study we have assumed, as other investigators who have approached this problem (Clarke et al., 1970), that chlorophyll concentration may be used as an index of amount of phytoplankton present.

The blue color of clear open ocean water has been attributed to selective scattering of blue light by water molecules and small particles in the water (Jerlov, 1968). Change of color from blue of open oceans to green in coastal regions was thought by Kalle (1938) to be due to soluble pigments of yellow color which are chemically related to humic acid. He referred to these as "yellow substances." Later research by Yenstch (1960) showed this color shift could also be caused by an increase in phytoplankton pigments (primarily chlorophyll). If one assumes that this is the case, i.e., that the color shift is due to phytoplankton, or that there is a direct relationship between phytoplankton and the yellow substance, then it would seem possible to determine phytoplankton (or chlorophyll) concentration from some analysis of water color.

Clarke et al. (1970) showed by comparison of spectra from water with high chlorophyll content to that with low chlorophyll that there is a decrease in upwelling blue light and an increase in upwelling green light with increasing chlorophyll content.

Photographic densitometric measurements of irradiance have been related to chlorophyll concentration in open ocean waters (Baig, personal communication). The technique used was to calculate ratios of blue to green density and relate these ratios to chlorophyll concentration. In the case of near-shore waters such as Mississippi Sound factors exist which raise questions regarding the applicability of this technique. These are: (1) turbid water with large sediment content, (2) high concentrations of phytoplankton which make scattering of light as well as absorption important, and (3) in shallow water, bottom reflectance may introduce errors. In order to assess the effectiveness of this technique we have made density measurements of photography collected during Mississippi Sound I and II experiments which had companion surface measurements of chlorophyll concentration. Density ratios of blue to green and blue to green times red were compared to surface measurements of chlorophyll concentration. Analysis of these data showed some relationship to chlorophyll; however, there was not enough general consistency to make the technique a useful tool for measuring chlorophyll in near-shore environments.

Film densities from photography taken during the Mississippi Sound II experiment were also compared to secchi extinction depths. A graph of red film density versus secchi extinction depth showed a slight trend toward higher values of film density with increasing secchi extinction depths (Figure 15). Since the densitometry was performed on positive transparencies, higher film density is equivalent to less energy. Thus, there is less upwelling red light as the water becomes clearer.

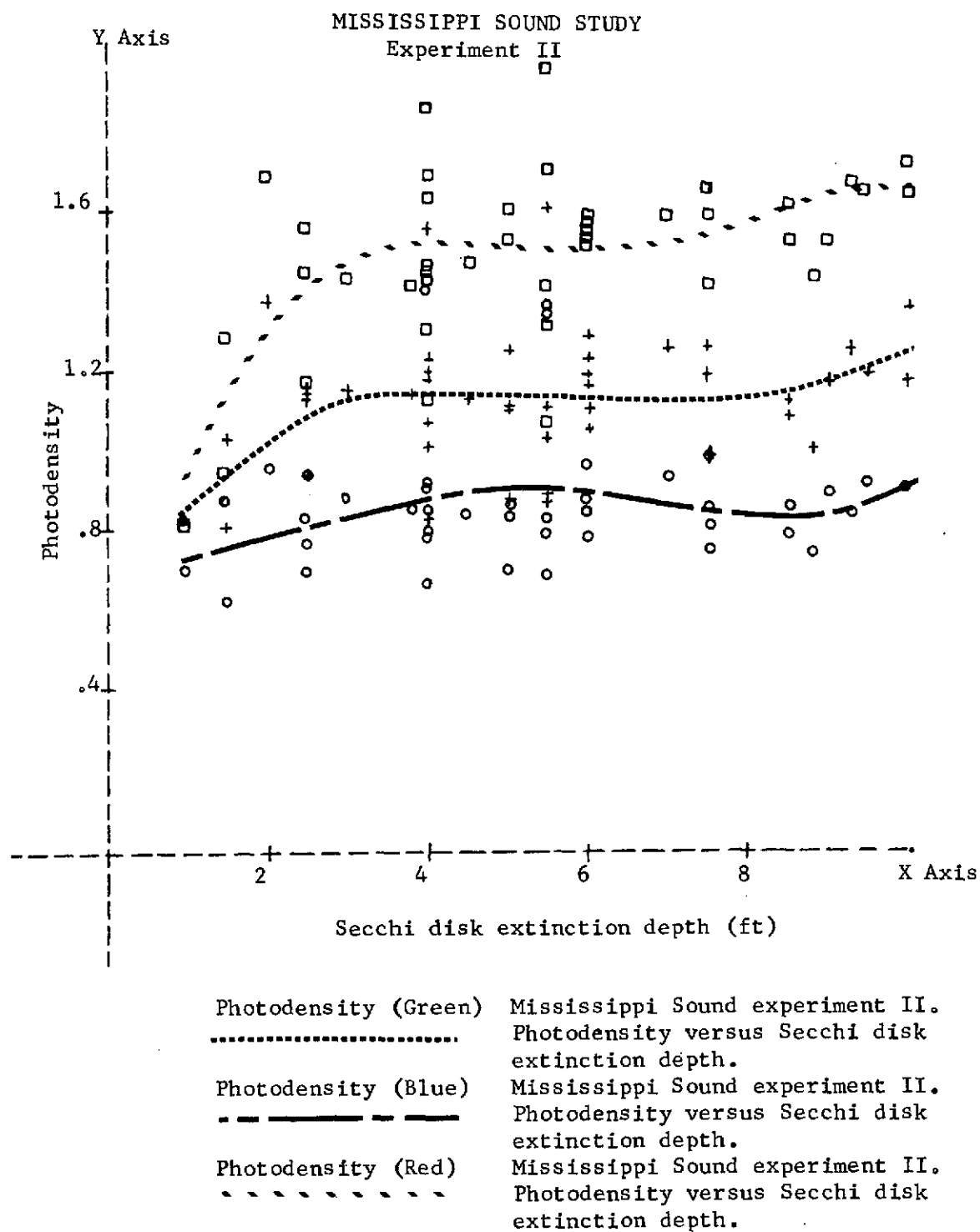


Fig. 15. Secchi disk extinction depth, Mississippi Sound Study experiment II, 10 November 1971.

At the outset of the study it was realized that color characteristics of the Mississippi Sound water would be influenced by a larger number of variables than open ocean water, and this would make the task of determining the chlorophyll content from upwelling light more difficult. What we didn't know was how severely this situation would limit the use of this techniques. Results of our experiments indicated that until some technique is developed which will take into account these other factors, this method has very restricted usefulness in Mississippi Sound and similar water bodies.

Photographic Mosaic: The high altitude (17,500 feet) flight paths flown by the NP3A aircraft during the Mississippi Sound II experiment were planned so complete areal coverage would be obtained from the RC-8 cameras and RS-14 infrared scanner. Two RC-8 cameras were used, one with color film and the other with black and white film filtered to favor transmission in the blue to green (480 to 550 millimicrons) portion of the spectrum.

Uncontrolled staple mosaics were constructed from both color and black and white photography. The mosaic made with black and white photography (Figure 16) was more interesting as "bottom" features as well as turbidity patterns were more clearly displayed than in the color photography.

Information pertaining to surface currents and locations of live oyster beds was inscribed on the mosaic. Oyster beds are shown by stippled areas. Their locations were obtained from information furnished by Mississippi and Alabama State agencies. Surface currents are shown by current vectors. These were measured by two methods: (1) drifting floats as described in the surface measurement section - these are represented by double line vectors; (2) by measuring the separation between two dye markers, one tethered to the bottom and the second drifting free with the current. These dye markers were packaged together with quick acting water soluble tape and dropped from a light aircraft. By knowing the time the package entered the water and the time the

OYSTER BEDS



DREDGING

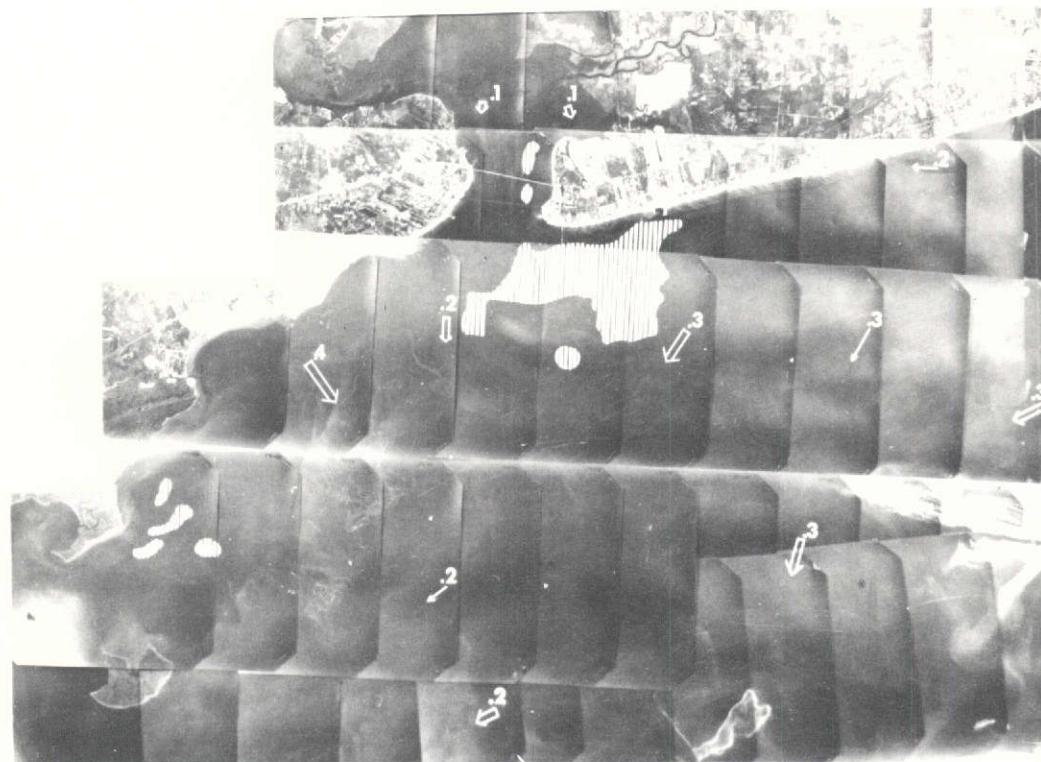
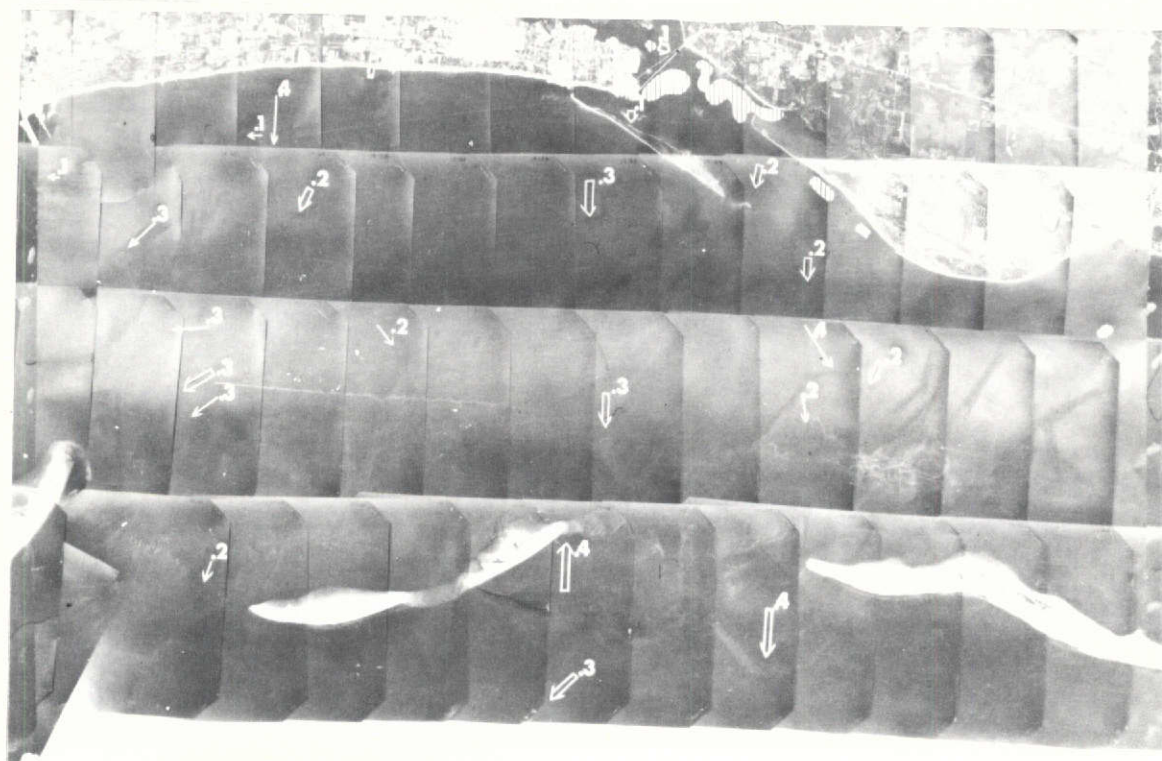


Fig. 16A. Mississippi Sound Study experiment II,
Photo-mosaic, 10 November 1971.



APPROXIMATE SCALE



Fig. 16B.

CURRENT MEASURED
WITH A BUOYANT FLOAT
CURRENT MEASURED
FROM DYE PLUMES

→ .3 knots
→ .2 knots

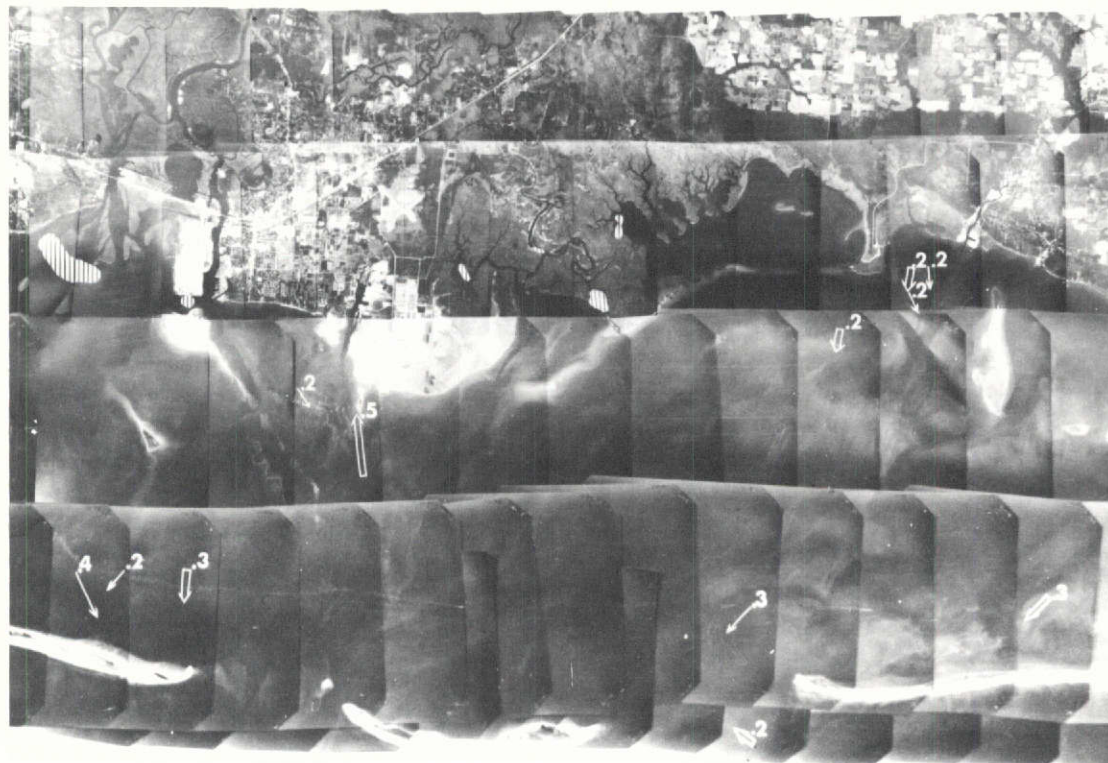


Fig. 16C.

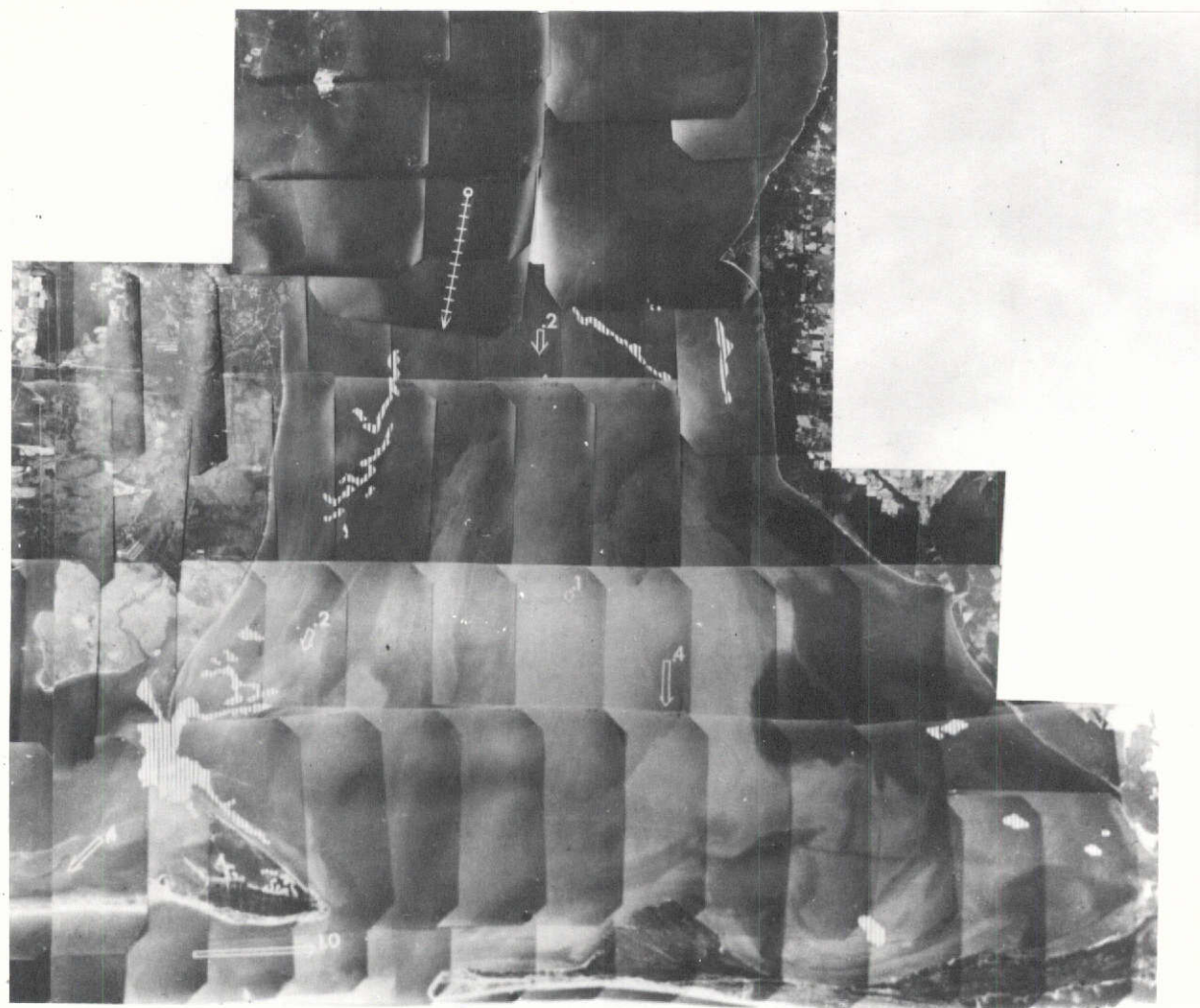


Fig. 16D.

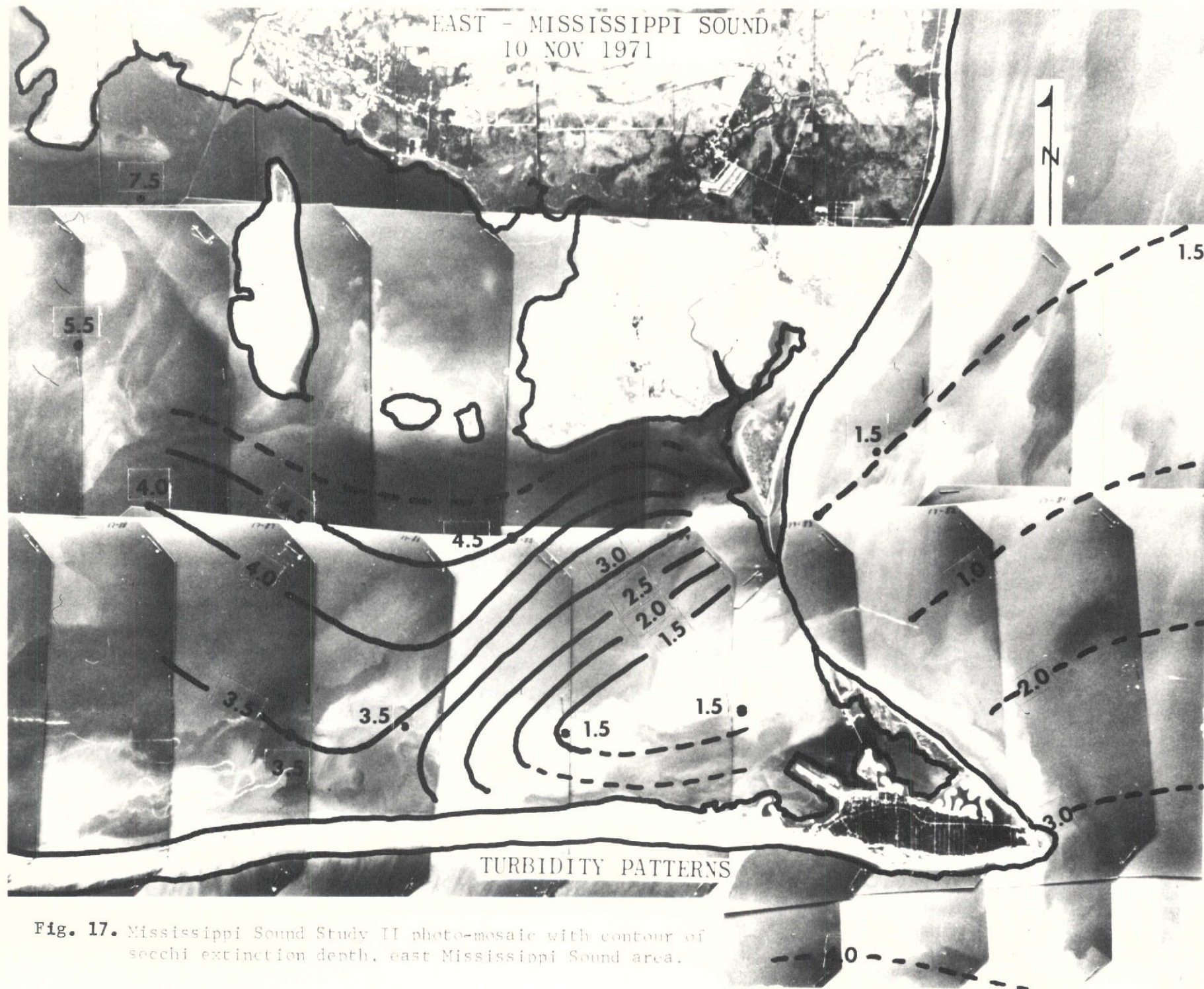


Fig. 17. Mississippi Sound Study II photo-mosaic with contour of secchi extinction depth, east Mississippi Sound area.

two dye markers were photographed, it was possible to determine time required for the observed separation to take place. From distance of separation and time interval, surface currents were calculated. Current velocities determined in this manner are represented on the photo-mosaic by single line vectors.

Turbidity patterns shown on this mosaic, especially those in Mobile Bay, were of interest. The water of Mobile Bay was more turbid, as shown by lighter tone in the photography and verified by secchi measurements (Figure 17), than adjoining water in Mississippi Sound and Gulf of Mexico. It was possible from the mosaic to trace water entering Mississippi Sound from Mobile Bay by difference in water color - a manifestation in this case of difference in turbidity. A sediment plume from a shell dredge in Mobile Bay was shown in the photography. A circle was placed at the location of the dredge and the position and length (approximately 6 miles) of the plume was indicated by an arrow with short perpendicular lines.

It was interesting to compare water color patterns shown in the photo-mosaics (Figure 16) with those shown in the mosaic of the RS-14 infrared scanner imagery (Figure 14). In the eastern part of Mississippi Sound there was an excellent correlation in patterns associated with water entering Mississippi Sound from Mobile Bay; however, as Mobile Bay water exited from Mississippi Sound through Petit Bois Pass, this correlation was not as pronounced. This was thought due to settling of sediment from Mobile Bay water as it passes along Dauphin Island in its course toward the Gulf of Mexico through Petit Bois Pass.

Microwave Radiometry - Remote Measurement of Salinity: Data from the L-band (21cm wavelength) of the MFMR obtained during the Mississippi Sound Experiments I, II and III were studied by Thomann (1972). He discusses theory of and corrections to passive microwave data used to determine salinity. A comparison of salinities and microwave response at stations along flight paths I, which is

from Thomann's paper, show generally good agreement (Figure 18). Salinity accuracies of 3-5⁰/oo were obtained. Thomann believed the accuracy was limited by the radiometer used. The microwave data shown in the figure was calibrated on the basis of surface measurements at stations A and B. Because of this, microwave response and surface salinity measurements are coincident at these stations.

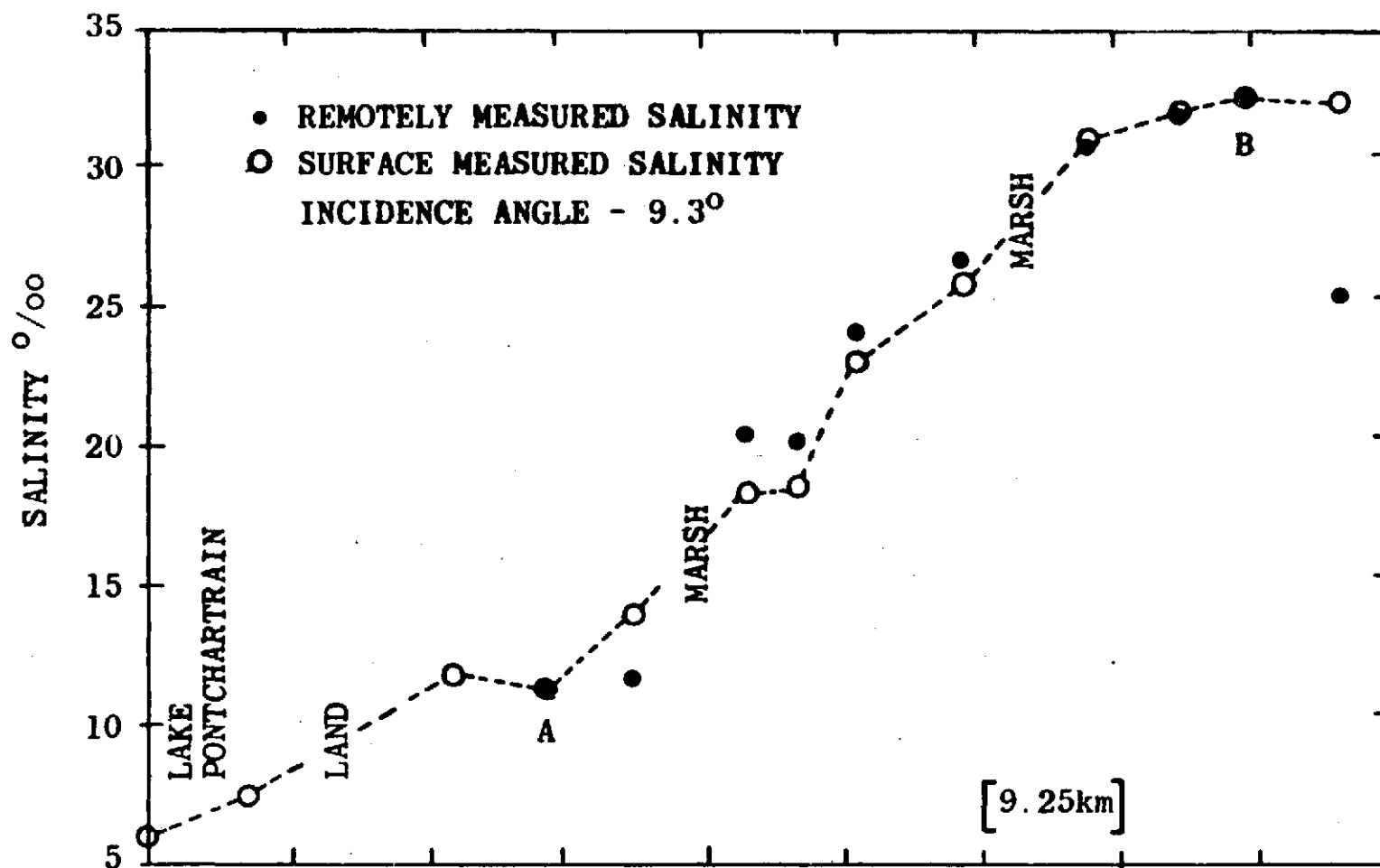


Fig. 18. Remote and surface measured salinity values obtained over Mississippi Sound on July 22, 1971 (From Thomann 1972).

V. SUMMARY AND CONCLUSIONS

The feasibility of conducting a study in which quasi-synoptic surface and remote measurements were made over an area of coastal water of approximately 1000 square miles during two separate experiments was demonstrated. The data collected allowed a comparison of remote and conventional measurements of temperature, salinity and chlorophyll content of the water of Mississippi Sound. Furthermore, variations shown by surface maps of these parameters were related to exchange of water between Mississippi Sound, Mobile Bay and the Gulf of Mexico.

Temperature maps of Mississippi Sound constructed from corrected PRT-5 measurements obtained during the first two experiments (22 July and 10 November 1971) compares well with maps constructed from surface measurements. The RS-14 infrared scanner imagery was shown to provide unique information regarding the surface temperature pattern. Calibration of the RS-14 scanner imagery permitted temperature differences as small as 0.5°C to be resolved.

The general question of radiative water temperature measurement was discussed, and reasons for lack of agreement between airborne radiative temperature and "bucket" temperature measured with a mercury thermometer were attributed to the effect of the atmosphere, nonblackness of the water surface and temperatures of the upper 0.02mm being unrepresentative of the average temperature of the upper few inches.

A mosaic of Mississippi Sound was constructed from photography collected during the Mississippi Sound II experiment. Densitometric measurements of photography from both the Mississippi Sound I and II experiments were analyzed in terms of the chlorophyll content of the water and secchi extinction depth. The effects of bottom reflection, inorganic sediment, and high chlorophyll content were thought responsible for the data having no consistent relationship

to chlorophyll content of the water. A slight relationship between photo-densities and secchi extinction depths was seen.

If the patterns shown by more than one of the parameters in a given area are considered, it brings to attention areas in the Sound which have special significance. The far western part of the Sound, for instance, was an area with low salinity during all three experiments; it was also an area of little temperature variation and low water clarity. All these factors seem to point to this area as not being directly influenced by influxes of Gulf water. In contrast, the areas adjacent to the passes have relatively high salinities, temperature biased toward the temperature regime in the Gulf, and high water clarity compared to the remainder of the water within the Sound.

It would seem that the Sound may be roughly divided into three major elements; the eastern end dominated by Mobile Bay inflow and related movement through Petit Bois Pass; the central region with the in-out Gulf flow through the passes, and the "sheltered" Horn Island area; and the western region which appears to be the most quiescent. This generalization is based on limited sets of data, and its degree of accuracy varies with the specific parameter under consideration. It does, however, provide a starting point for defining the hydrology of the Sound and assessing the ability of remote sensing techniques to measure its characteristics.

APPENDIX (1)

Contents of Boat Kit

The contents of a standard boat kit are listed in Table A1. Some of the items listed in Table A1 need no further comment; however, some require further discussion.

The boat markers were included so that each of the surface measurement vessels could be easily identified from the aircraft. The markers used for the July mission were orange styrofoam sections with dimensions 2.5" x 20" x 9'. Four of these sections were linked together to make a marker 20" x 36'. This made a very visible marker, but proved to be somewhat fragile for this type of operation.

They were replaced by an orange 1/4" x 30" x 30' piece of flexible polyester which proved to be much more convenient to handle and more durable.

The ice chest was furnished so that the water samples could be refrigerated and kept at a cool fairly constant temperature in order to minimize changes which might take place between the time the sample was taken and when it could be analyzed. This was particularly critical in the case of samples analyzed for chlorophyll content which was one of the parameters of particular interest.

The plastic bucket was used to collect a water sample from the vicinity of the water surface. The temperature of this water was then measured with the mercury thermometer. The values obtained were taken as surface temperature; however, in comparing them to radiometric temperature some obvious inaccuracies are introduced. Nevertheless, faced with the problem of equipping 43 boats to take consistent surface temperature data, this seemed to be the best way to go about it.

Table A1. Contents of a standard boat kit.

Boat marker
Ice chest
Plastic bucket
Data sheets
Instructions
Numbered sample bottles
Sling psychrometers
Thermometer (mercury)
Secchi disk

APPENDIX (2)

Laboratory Procedures

Water samples were taken in pint and quart size polypropylene bottles. Numbers were engraved on the bottles for identification. Plastic buckets (2 1/2 gal.) were used in collecting surface samples. Depth samples were obtained with B.O.D. bottles rigged so the lid could be released at the proper depth. While on the boats the samples were kept cool and dark in styrofoam ice chests and later picked up by a refrigerated van and delivered to the Mississippi State University Laboratory at Mississippi Test Facility. Samples were analyzed immediately or refrigerated until time of analysis. A list of parameters for which analyses were performed is included in Table A2.

Salinities were run with a Bissett-Berman Laboratory Salinometer. Standard (35⁰/oo) sea water was used as a reference, and salinities were determined from the conductivity ratio of the sample to that of the standard. Temperature and instrument drift corrections were made according to the Bissett-Berman Instruction Manual.

Water samples at each station were analyzed for chlorophyll content, which gives a measure of the phytoplankton present. The technique used was essentially that proposed by SCOR-UNESCO working group 17 in Determination of Photosynthetic Pigments in Sea-Water, UNESCO, Paris, 1969. Each water sample for chlorophyll analysis was filtered through a millipore 0.45 micron acetate filter. Filtering started as soon as the first samples were delivered and continued until all were filtered at approximately 2 a.m. on the morning of the day following the experiment. Thus, no sample was held more than 18 hours before filtering. The filters and their residue were stored at -5°C over activated silica gel. Each filter and its residue was ground in a teflon tissue grinder. Ninety percent

acetone was used as the extracting agent. The acetone homogenates were stored in the dark for ten minutes, then centrifuged at 2000 g for forty minutes instead of the recommended ten minutes because the extract was too turbid. The volume of each extract was recorded and the absorption spectrum of the chlorophyll extract measured against a blank acetate filter dissolved in 90% acetone. The measurements were made on a Carey 17 Spectrophotometer.

The absorption spectra were indexed at 750, 663, 645, and 630 mμ. The absorption at 663, 645, and 630 mμ was corrected by comparison with the absorption of the "reference blank" at 750 mμ. These corrected values are used in the following formula to determine chlorophyll a.

$$\text{chl } \underline{a} = (11.64 \times e_{663} - 2.16 \times e_{645} + 0.10 \times e_{630}) \times$$

$$\frac{\text{ext (ml)}}{\text{vol (l)}} \times \frac{1}{\text{absorption cell light path (cm)}}$$

where e_{663} = absorption at 663 mμ

e_{645} = absorption at 645 mμ

e_{630} = absorption at 630 mμ

ext = extract volume

vol = volume of sample

Scientists from Mississippi State University performed the following water analyses.

Light transmission measurements were made using a Bausch and Lomb Spectronic 20 at a wavelength of 625 mμ.

Primary productivity and metabolic activity measurements were made by filling two 300 ml B.O.D. bottles with samples and the dissolved oxygen (in one of the bottles) determined using a YSI portable oxygen meter. The bottles were immediately stoppered and one of the pair covered with aluminum foil. Both bottles were placed in a circulation water bath (20 gal. aquarium) at 26°

$\pm 1^{\circ}\text{C}$, incubated for eight hours, and the dissolved oxygen determined on both bottles.

Turbidity measurements were conducted on a Coleman Nephcolorimeter.

The total coliform population was estimated using the multiple-tube fermentation technique as described in Standard Methods for the Examination of Water and Wastewater, 12th Ed. 1965. One fifty ml portion, five 10 ml portions, five 1 ml portions and five 0.1 ml portions of each sample were employed.

The pH determinations were made using a Coleman Model 12 pH meter.

Chloride ion and salinity were measured by filtering the sample and titrating 2 ml with standardized silver nitrate solution. The method used is described in Standard Methods for the Examination of Water and Wastewater, 12th Ed., P. 86, with the exceptions that the silver nitrate solution was approximately 1/10N and the indicator used as dichlorofluorescene. Salinity was calculated according to the Encyclopedia of Oceanography, 1st Ed., P. 72: $\text{Salinity } (^{\circ}/\text{oo}) = 0.03 + 1.805 \times \text{Chlorinity}$.

Sodium, potassium, calcium, magnesium, and iron concentrations were determined using atomic absorption spectrophotometry.

Phosphate was determined by using the Stannous Chloride Method for Orthophosphate as described in Standard Methods for the Examination of Water and Wastewater, 12th Ed., P. 234. A 50 ml sample was used halving all reagent quantities in this procedure.

The Brucine Method was used for the nitrate analysis as described in Standard Methods for the Examination of Water and Wastewater, 12th Ed., P. 198.

In determining suspended solids tared Gelman Type A 46 mm fiber discs were placed on millipore sterifil filter units. While vacuum was applied 1000 ml

of samples were passed through the filter followed by 100 ml of distilled water. The filter was dried in a drying oven at 103-105°C for one hour, then desiccated for thirty minutes, and reweighed.

In measuring total solids one hundred ml aluminum dishes were numbered and placed in a drying oven at 103-105°C, cooled in a desiccator, and weighed. Ten ml of samples were then placed in a dish, evaporated, and dried in a drying oven at 103-105°C, cooled in a desiccator and weighed.

TABLE A2. Laboratory analysis of water samples.

Metabolic Activity

Turbidity

Coliform

pH

Chloride Ion

Sodium

Potassium

Calcium

Magnesium

Iron

Phosphate

Nitrate

Total Solids

Suspended Solids

APPENDIX (3)**Tide Records**

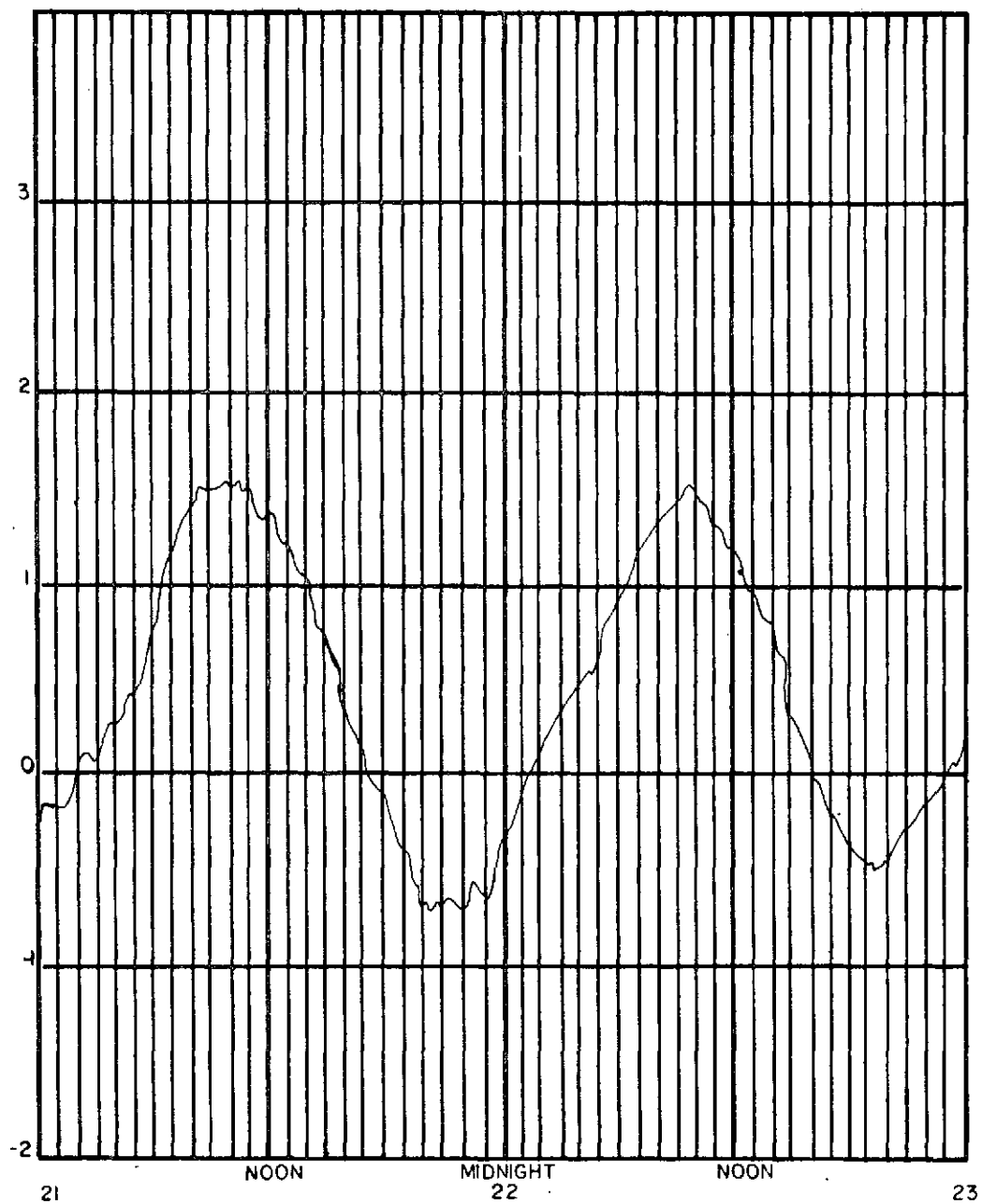


Fig. A1. Gage zero - 0.23 MSL

Tides at Dauphin Island, Alabama, 21, 22 July 1971.

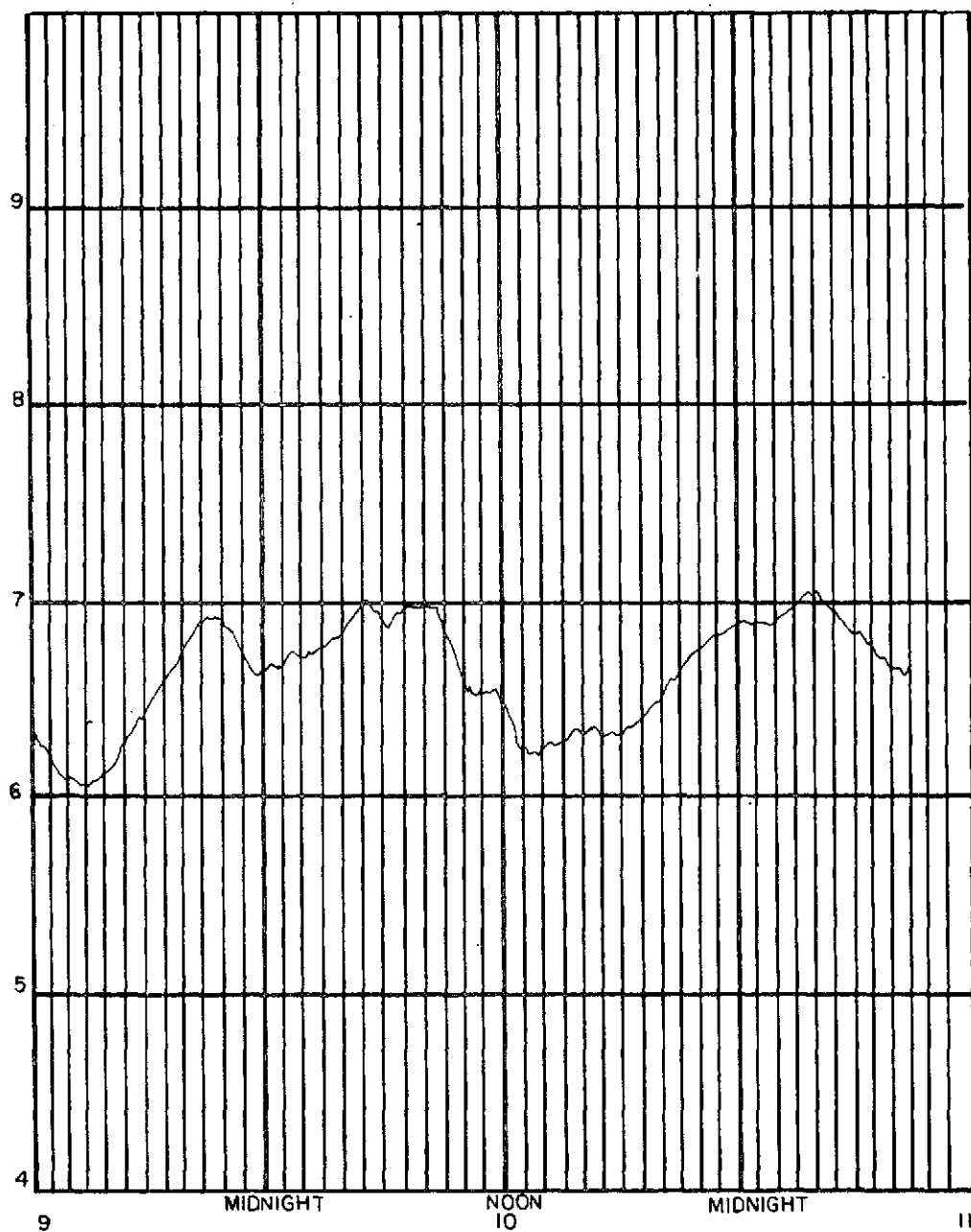


Fig. A2. Gage zero - (not surveyed)

Tides at Biloxi, Mississippi, 10 November 1971.

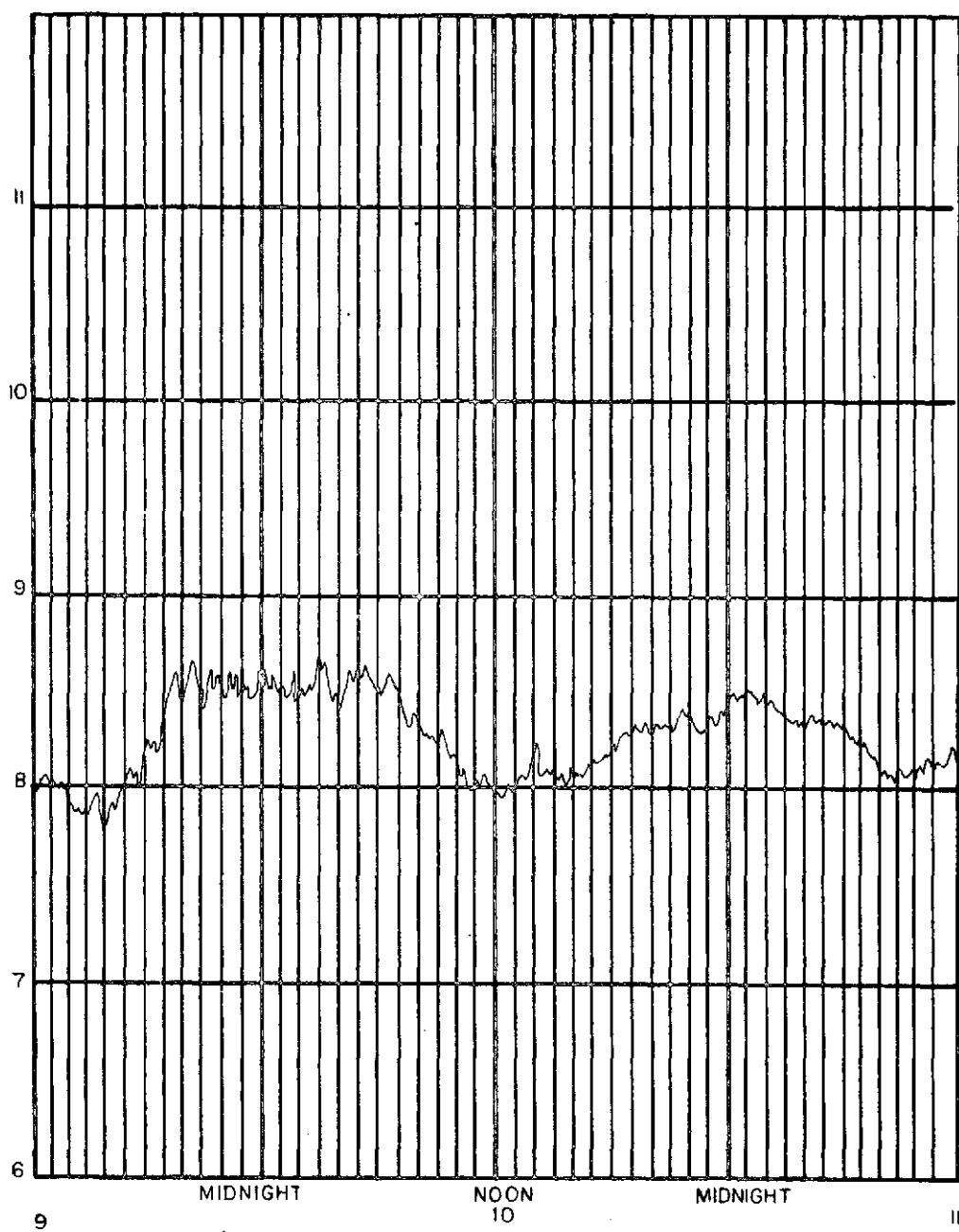


Fig. A3. Gage zero - (not surveyed)
Tides at Dauphin Island, Alabama
9, 10, 11 November 1971.

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